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TRANSPORT, FATE AND GEOCHEMICAL INTERACTIONS OF MERCURY, CADMIUM AND OTHER INORGANIC POLLUTANTS IN THE COASTAL LITTORAL-SALT MARSH ENVIRONMENT OF THE SOUTHEASTERN UNITED STATES

Skidaway Institute of Oceanography

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Submitted by

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May, 1973

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TABLE OF CONTENTS

Page No.

I. SUMMARY 1

II. INTRODUCTION 3

III. FIELD STUDIES 5

A. Chemical Studies 5

1. Concentrations of Dissolved Oxygen SO_4, NH_4, NO_3 and PO_4 in Southeastern Rivers and Estuarine Waters 16
2. Concentrations of Dissolved Iron, Manganese, Copper, Mercury, Cadmium and Lead in Southeastern Estuaries 23
3. Concentrations of Particulate Iron, Manganese, Copper, Mercury, Cadmium, Lead and Zinc in Southeastern Estuarine Waters 32
4. Annual Discharge of Iron, Manganese, Copper, Mercury, Cadmium and Lead by Southeastern Rivers 48
5. Concentrations of Fe, Mg, Cu, Hg, Cd, Pb and Zn in Estuarine and Salt Marsh Sediments 52

B. Hydrographic Studies 61

IV. LABORATORY STUDIES 72

A. Characterization of Dissolved Organic Matter 72

B. Flocculation Studies 87

C. Complexation of Metals by Organic Acids 89

V. TENTATIVE MODEL OF THE TRANSFER OF METALS TO AND THROUGH THE COASTAL LITTORAL-SALT MARSH ESTUARINE SYSTEM 91

VI. REFERENCES 97

Appendix I 99

Appendix II 124

LIST OF TABLES

Page No.

Table 1 Mean Concentrations of Metals in Solution in Southeastern Rivers During May Through December 1972 24

Table 2 Mean Concentrations of Metals in Solution in Southeastern Estuaries During May Through December 1972 25

Table 3 Average Total Metal Concentration in Suspended Sediment of Southeastern Atlantic Rivers 39

Table 4 Average Total Metal Concentration in Suspended Sediment of Southeastern Atlantic Estuaries 40

Table 5 Metal Transport by Southeastern Rivers 51

Table 6 Per Cent Particulate of Total Metal Concentrations in River Waters 53

Table 7 Average Metal Concentrations in Marsh Cores 56

Table 8 Metal Concentrations in Charleston Harbor Sediment Samples ... 60

Table 9 Carbon 14 Ages of Marsh Sediments 62

Table 10 Accumulation Rate of Metals in Salt Marsh Sediments 64

Table 11 Dissolved Organic Data 74

Table 12 Elemental Analyses of D. O. M. 76

Table 13 Oxygen Containing Functional Group Analyses 77

Table 14 Annual Fluxes of Metals 96

LIST OF FIGURES

Page No.

Figure 1. Study Area showing location of major river discharges and estuaries.. 4

Figure 2. Sampling Station locations in Winyah Bay Estuary - Pee Dee and Black Rivers.................................. 6

Figure 3. Sampling Station locations on Santee River Estuary 7

Figure 4. Sampling Station locations on Cooper River Estuary 8

Figure 5. Sampling Station locations on Savannah River 9

Figure 6. Sampling Station locations on Ogeechee River Estuary 10

Figure 7. Sampling Station locations on Altamaha River Estuary 11

Figure 8. Sampling Station locations on Satilla River Estuary............ 12

Figure 9. Sampling Station locations on St. Johns River Estuary 13

Figure 10. Variations in Dissolved Oxygen in Southeastern Estuaries...... 17

Figure 11. SO_4 versus salinity for Southeastern Estuaries................ 19

Figure 12. Variation in ammonia concentrations in Southeastern Estuaries . 20

Figure 13. Variation in nitrate concentrations in Southeastern Estuaries ... 21

Figure 14. Variation in phosphate concentrations in Southeastern Estuaries.. 22

Figure 15. Variation in iron concentration with salinity.................. 26

Figure 16. Variation in manganese with salinity 27

Figure 17. Variation in iron with pH................................. 28

Figure 18. Variation in manganese with pH 29

Figure 19. Iron versus manganese in southeastern river waters. 31

Figure 20. Season variations in copper concentrations in Southeastern Estuaries.. 33

LIST OF FIGURES (continued)

Page No.

Figure 21. Seasonal variations in lead concentrations in Southeastern Estuaries 34

Figure 22. Seasonal variations in cadmium concentrations in Southeastern Estuaries 35

Figure 23. Seasonal variations in mercury in Southeastern Estuaries 36

Figure 24. Seasonal variations in mercury in coastal waters 37

Figure 25. Iron in particulate matter of river versus that of estuarine water 41

Figure 26. Zinc in particulate matter of river versus that of estuarine water 42

Figure 27. Mercury in particulate matter of river versus that of estuarine water 43

Figure 28. Cadmium in particulate matter of river versus that of estuarine water 44

Figure 29. Lead in particulate matter of river versus that of estuarine water 45

Figure 30. Copper in particulate matter of river versus that of estuarine water 46

Figure 31. Total Organic Carbon in particulate matter of river versus that of estuarine water 47

Figure 32. Copper versus TOC in southeastern river waters 49

Figure 33. Copper versus TOC in southeastern estuarine waters 50

Figure 34. Location of Marsh Sediment Coring Stations 55

Figure 35. Mercury versus total organic carbon for salt marsh sediments 58

Figure 36. Location of bottom sediment samples in Charleston Harbor 59

Figure 37. C^{14} age versus depth in two salt marsh sediment cores 63

LIST OF FIGURES (continued)

Page No.

Figure 38. Location of Hydrographic Study Area........................ 65

Figure 39. Offshore Station Locations................................ 66

Figure 40. Station Locations in Winyah Bay........................... 68

Figure 41. General Oceanics Model 2010 Recording Current Meter........ 69

Figure 42. Meter Mounting System..................................... 70

Figure 43. Gel filtration of DOM fractions........................... 78

Figure 44. Infrared spectra of DOM................................... 83

Figure 45. Tentative Model for the Transfer and Fate of Metal to and through the Coastal Littoral-Salt Marsh System 93

I. SUMMARY

1. Iron, manganese, copper, mercury, cadmium and lead concentrations in estuaries of eight major rivers of the Southeastern Atlantic Coast have been determined on a bi-monthly basis between May and December 1972. These will be obtained through May 1973.

2. In addition, SO_4, NH_4, NO_3 and PO_4 concentrations have also been obtained for the same estuaries during this period.

3. No significant seasonal patterns in the concentrations of SO_4, NH_4, NO_3 or PO_4 have been observed.

4. Of the metals only mercury and cadmium show seasonal patterns in concentration in solution.

5. Observations of metal concentrations in particulate phases suggest that copper and possibly lead are related to total organic carbon. Both metals may be released from particulate material upon transport into the marine environment.

6. In salt marsh sediments mercury concentrations are related to total organic carbon. The rate of accumulation of all the metals studied has been obtained with

$$Fe > Mn > Pb > Cu > Cd > Hg$$

7. The rate of input of metals to the system has been tentatively obtained with

$$Fe > Mn > Pb > Cu > Cd > Hg$$

the relative proportion of the metal lost from the system due to sedimentation compared to its input follows the same trend.

8. Preliminary results of studies of dissolved organic matter characteristics and flocculation are presented. The design of studies to determine characteristics of metal complexing with organic acids is also presented.

9. A tentative model for metal transport to and fate in the coastal littoral-salt marsh system is discussed in relation to preliminary data.

10. Hydrographic studies of Winyah Bay and adjacent coastal waters have been almost completed.

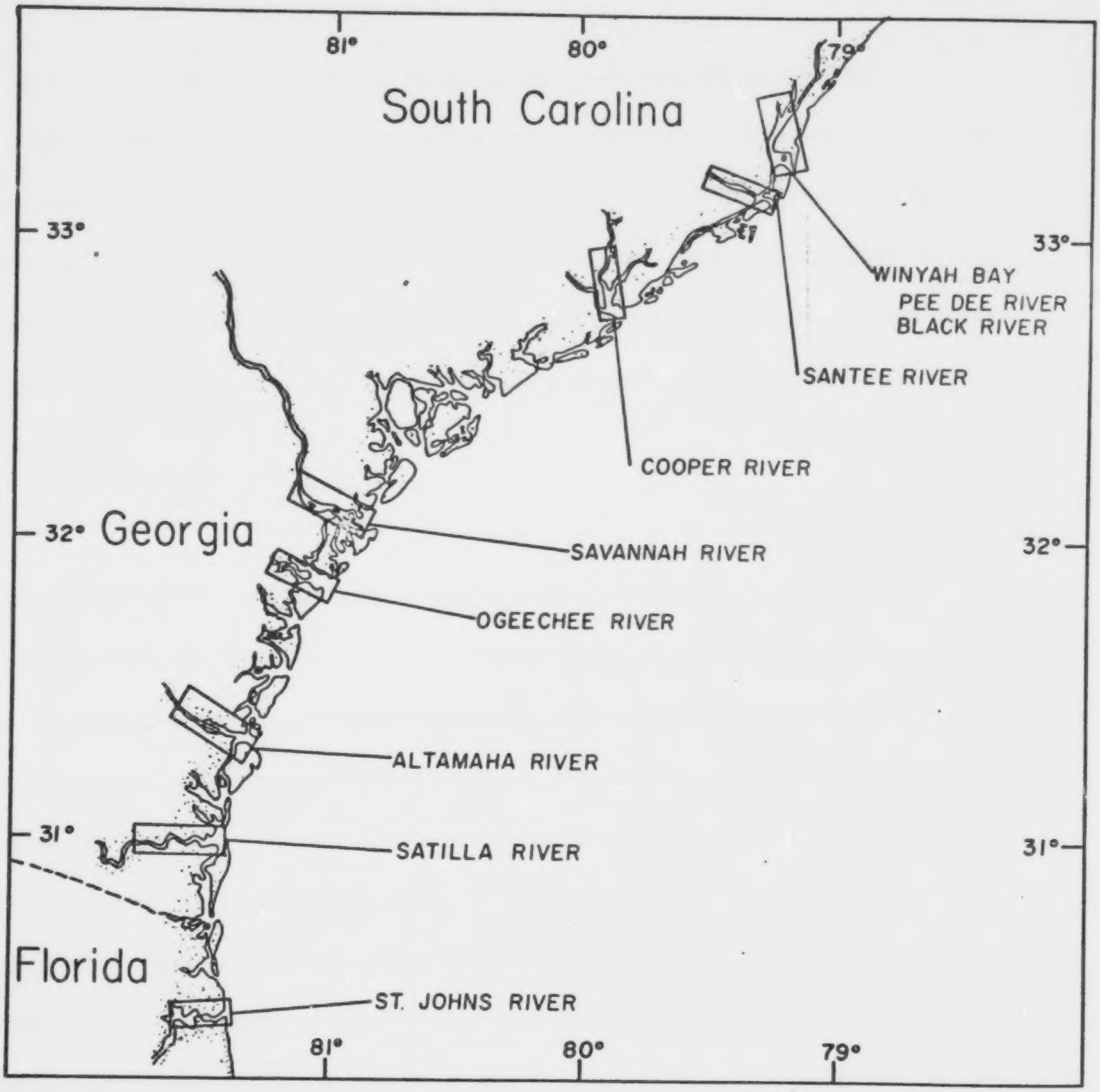
II. INTRODUCTION

The following report is based on results of research under EPA Project Number R-800372 for the period from 1 May 1972 to 30 April 1973. This covers the first year of the three year project. The purpose of the total project is to study the transport, fate and geochemical interactions of heavy metals being transported into the littoral salt marsh environment of the Southeastern United States Coast between Georgetown, South Carolina and Jacksonville, Florida (Figure 1).

The first year of research on this project has involved field and laboratory studies. The field studies provide a data base for the southeastern estuarine and littoral area and also elucidate geochemical interactions important to heavy metal transport and fate. The laboratory studies on the other hand are designed to elucidate more specific aspects and characteristics of geochemical interactions. The laboratory studies are also designed to better characterize parts of the environment under study.

The ultimate goals of the field and laboratory studies are as follows:

1. To develop a data base for the concentration of heavy metals in the salt marsh-littoral environment of the Southeastern United States and elucidate their variations in both time and space.
2. Determine the flux of metals into and through this system.
3. Establish the significance of salt marsh sediments as a sink for the various heavy metals.
4. Elucidate the form in which metals enter the estuarine environment and changes they undergo during transport.
5. Elucidate processes, both chemical and physical, responsible for the distribution, transport and fate of heavy metals in this environment.



81°
80°
79°
South Carolina
33°
32°
31°
Georgia
Florida
WINYAH BAY
PEE DEE RIVER
BLACK RIVER
SANTEE RIVER
COOPER RIVER
SAVANNAH RIVER
OGEECHEE RIVER
ALTAMAHA RIVER
SATILLA RIVER
ST. JOHNS RIVER

Figure 1. Study Area showing location of major river discharges and estuaries.

7. Develop a model for the non-biological transport of heavy metals through the salt marsh-littoral environment of the Southeastern United States.

III. FIELD STUDIES

The field studies are primarily designed to establish the data base for the variations in metal concentrations in time and space in the rivers, estuaries and coastal salt marshes of the Southeastern Atlantic Coast. Field studies have also included initial investigations into the circulation patterns in coastal areas adjacent to river discharges. The purpose of these studies is to establish the transport regime which will influence the distribution of metals along shore subsequent to their input into coastal waters.

A. Chemical Studies

In the chemical studies primary attention has been given to the heavy metals iron, manganese, copper, mercury, cadmium and lead and their distribution in the areas shown in Figure 1. The studies involve sampling of the major southeastern river estuaries on a bi-monthly basis. The stations where samples are collected are shown for each estuary in Figures 2 through 9. These stations cover the fresh water-salt water interface so that changes in metal concentrations and their chemical characteristics can be followed with salinity to elucidate geochemical interactions such as exchange processes upon initial entry of metals in the river discharge. In May 1973, the last of seven bi-monthly sampling trips will be completed for each of these estuaries. On each trip water and suspended sediment samples are collected and analyzed for heavy metals so that seasonal variations and variations related to salinity changes

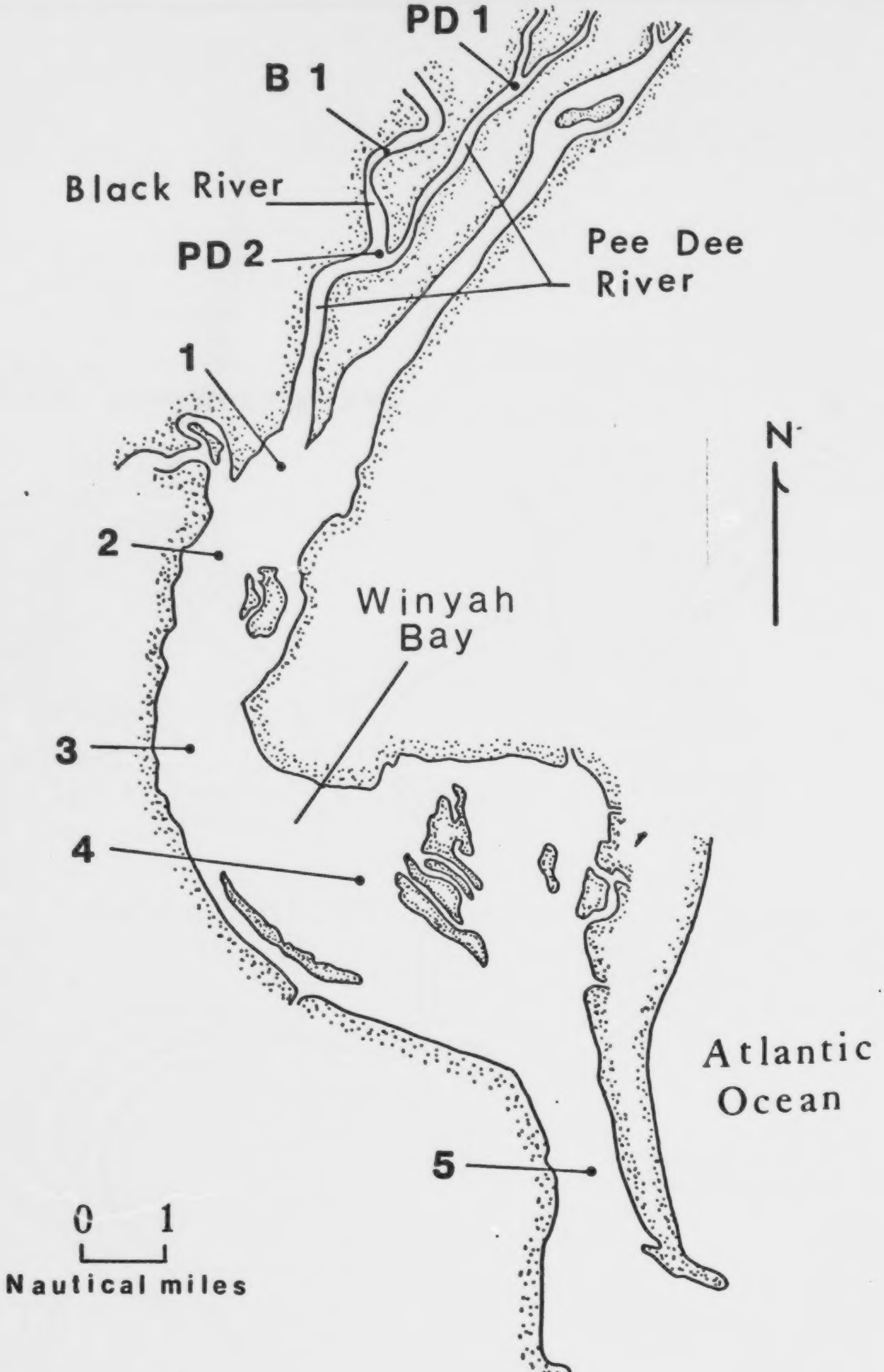

PD 1
B 1
Black River
PD 2
Pee Dee River
1
2
Winyah Bay
3
4
Atlantic Ocean
5
N
0 1
Nautical miles

Figure 2. Sampling Station locations in Winyah Bay Estuary - Pee Dee and Black Rivers.

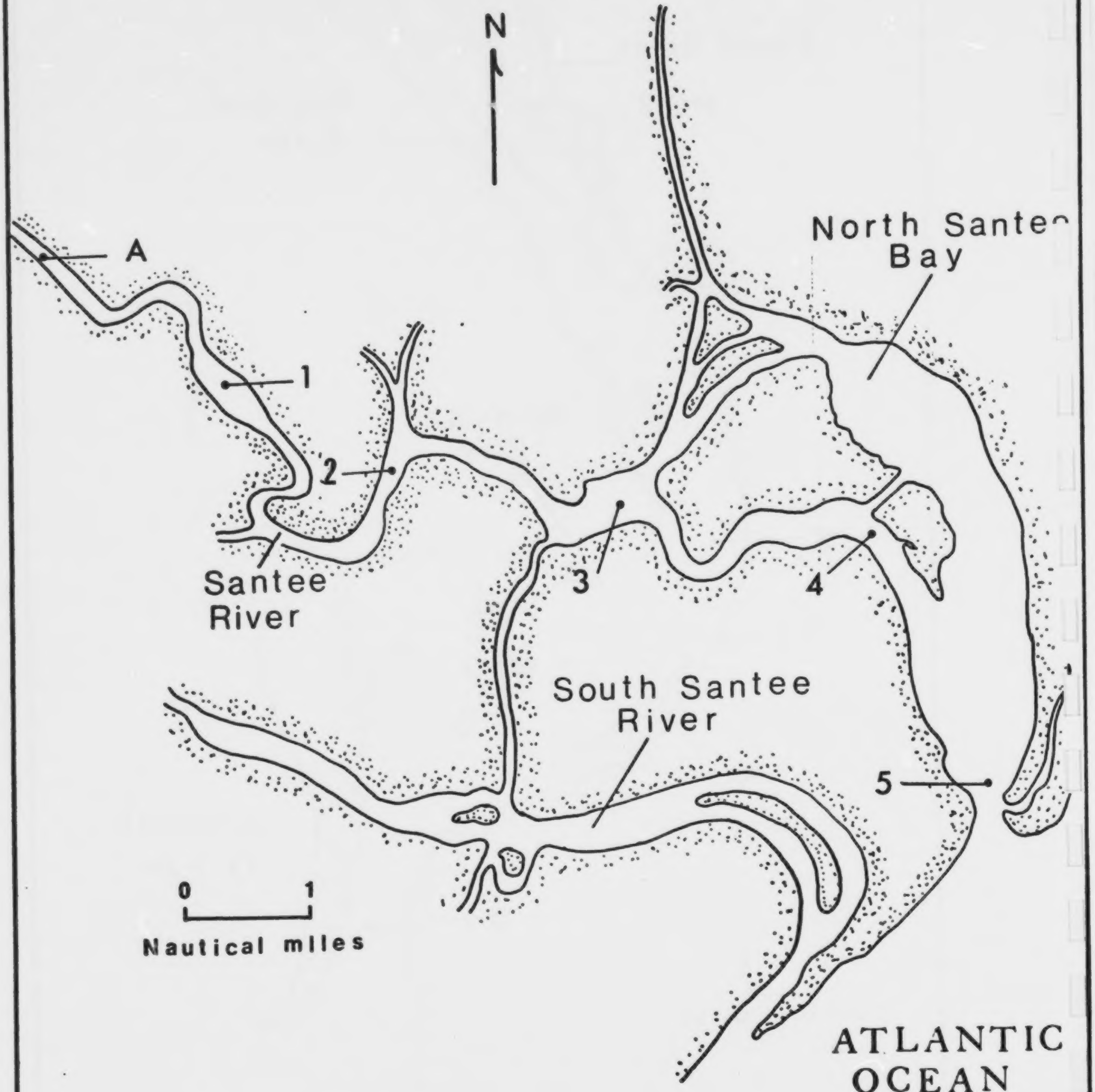

N
A
1
2
3
4
5
North Sante
Bay
Santee
River
South Santee
River
0
1
Nautical miles
ATLANTIC
OCEAN

Figure 3. Sampling Station locations on Santee River estuary.

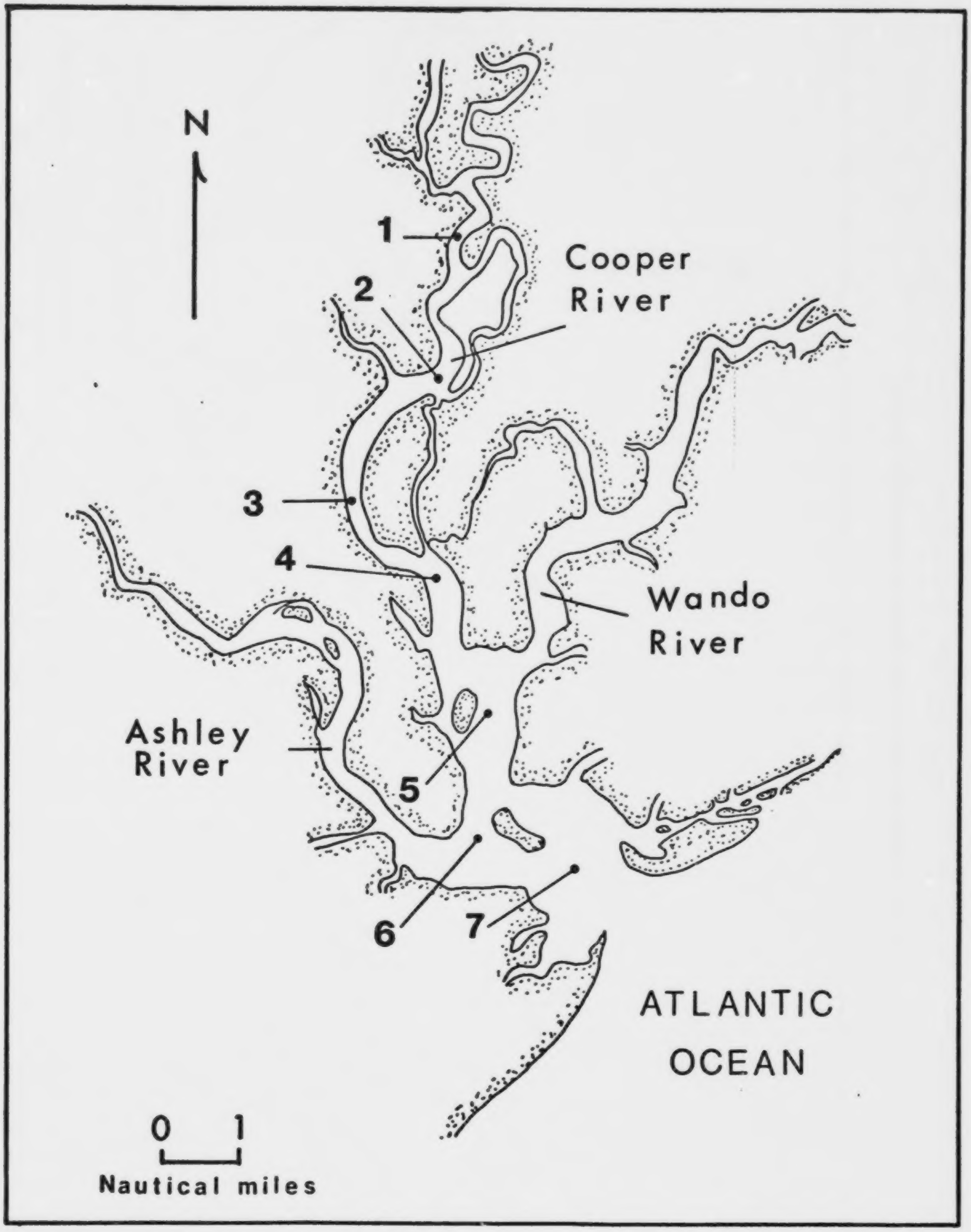

N
1
2
3
4
5
6
7
Cooper River
Wando River
Ashley River
ATLANTIC OCEAN
0
1
Nautical miles

Figure 4. Sampling Station locations on Cooper River Estuary

Figure 5. Sampling Station locations on Savannah River.

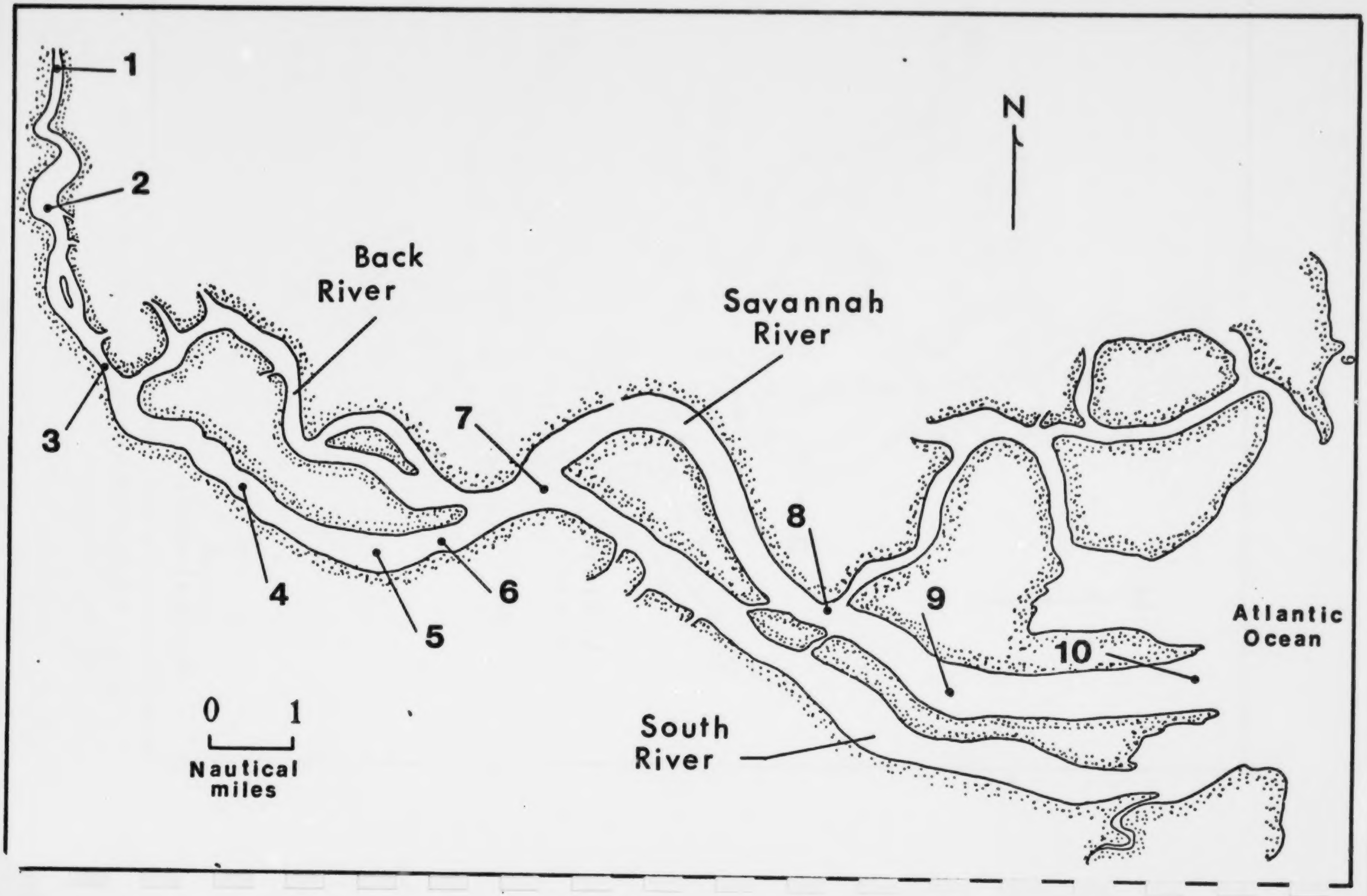

1
2
3
4
5
6
7
8
9
10
Back River
Savannah River
South River
Atlantic Ocean
N
0 1
Nautical miles

Figure 6. Sampling station locations on Ogeechee River Estuary

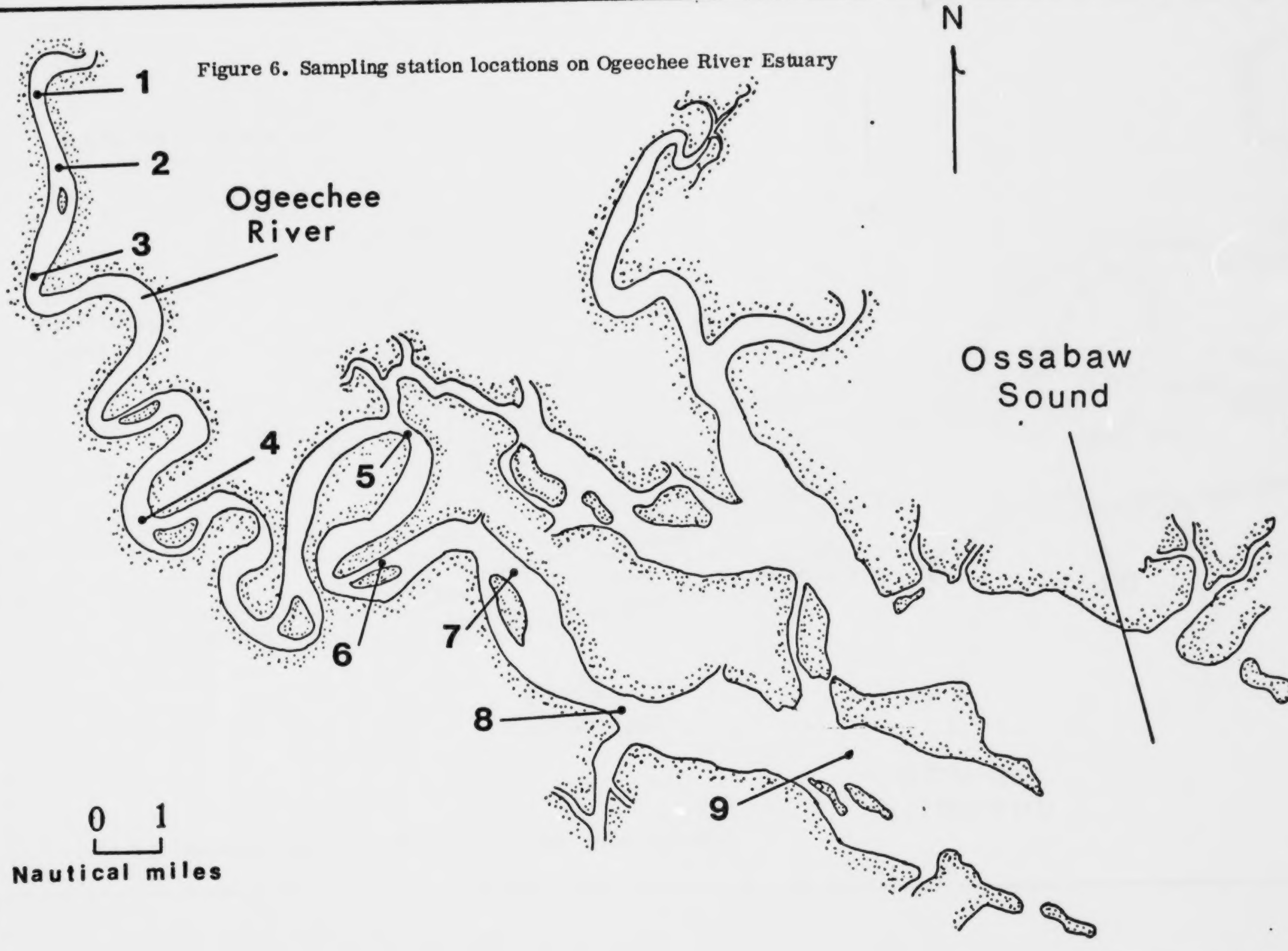

N
1
2
3
4
5
6
7
8
9
Ogeechee River
Ossabaw Sound
0 1
Nautical miles

Figure 7. Sampling station locations on Altamaha River Estuary.

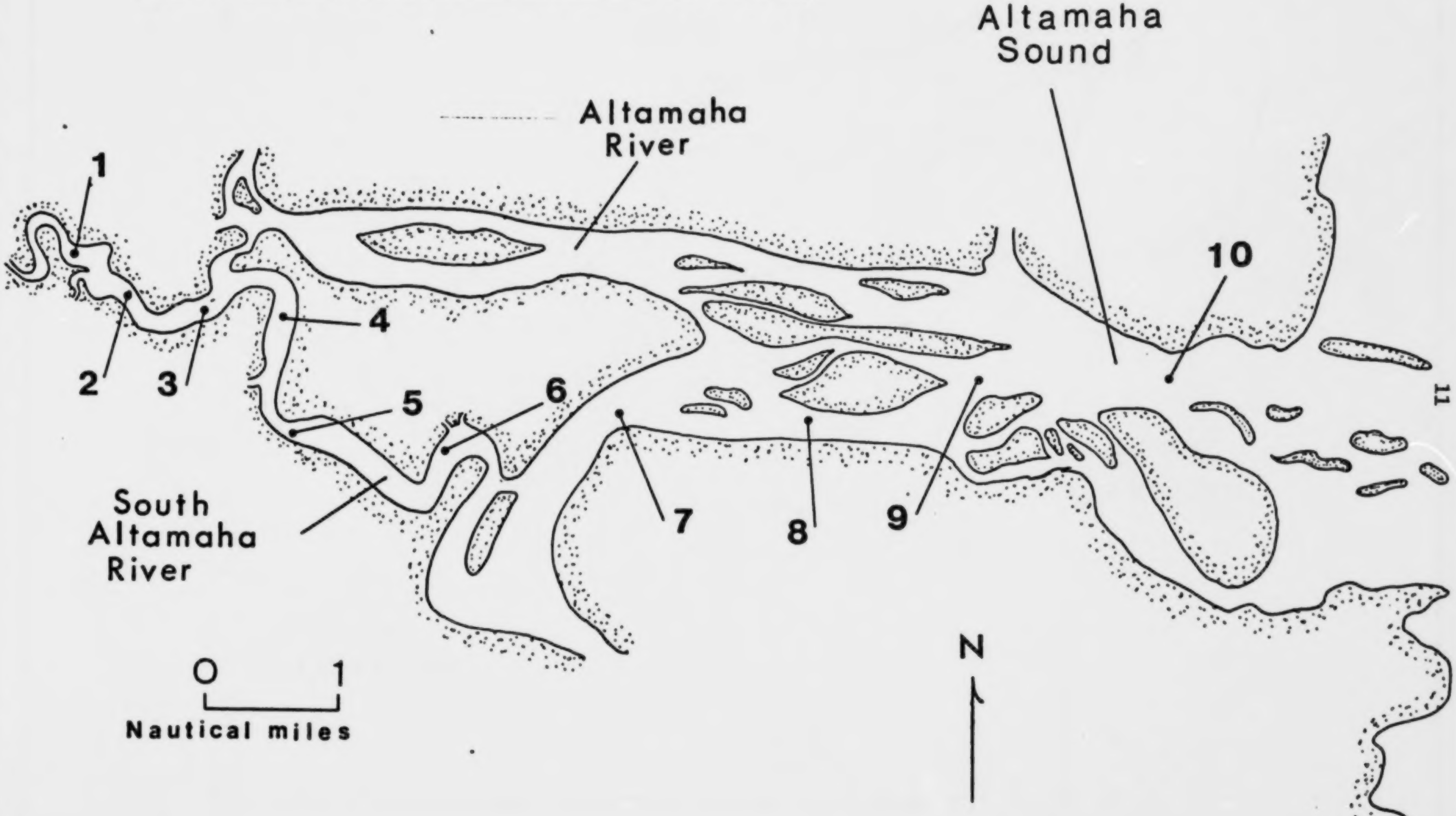
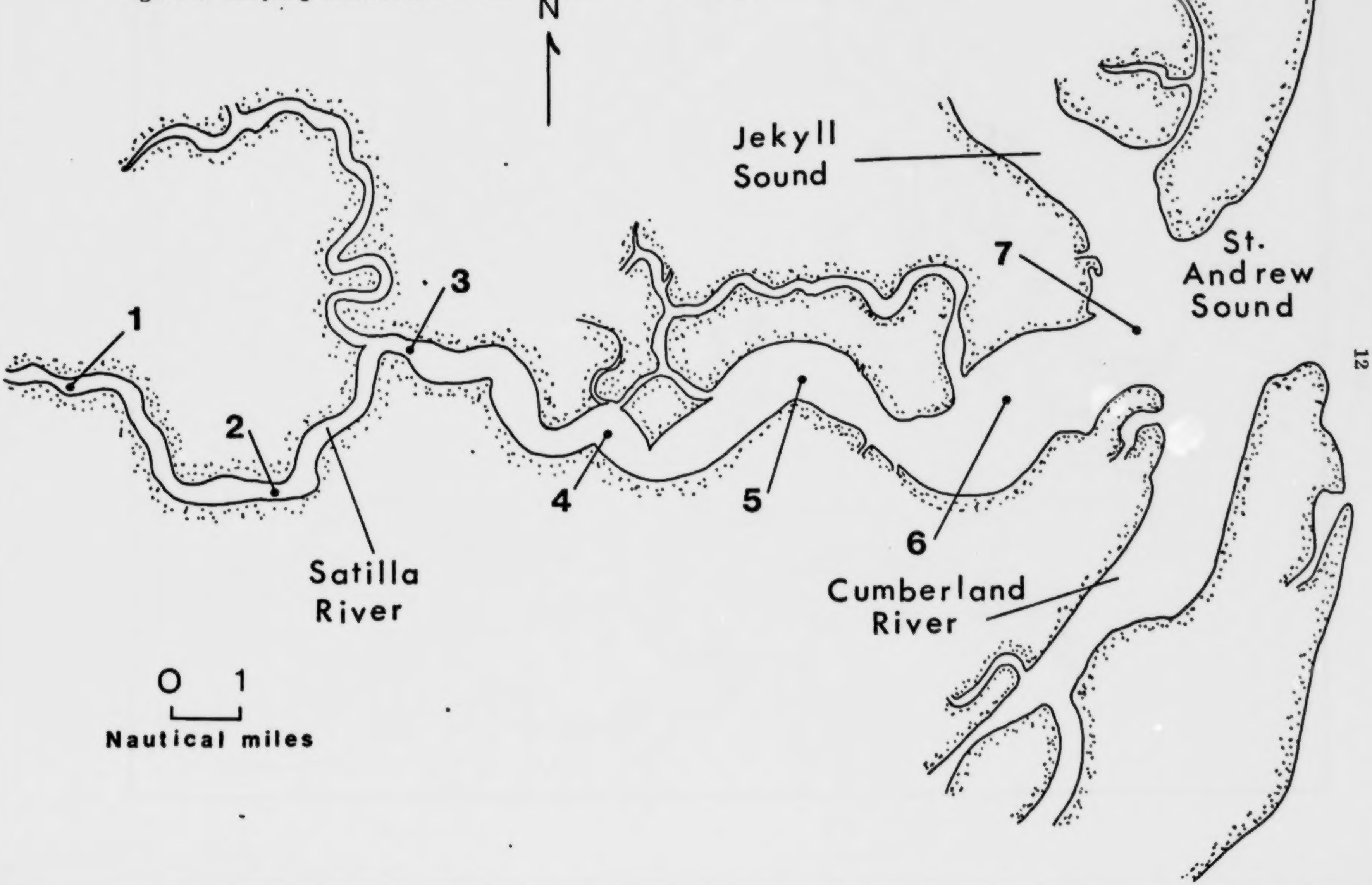

Altamaha River
Altamaha Sound
1
2
3
4
5
6
7
8
9
10
South Altamaha River
0
1
Nautical miles
N

Figure 8. Sampling station locations on Satilla River Estuary.


N
Jekyll Sound
St. Andrew Sound
7
1
3
2
4
5
6
Satilla River
Cumberland River
0 1
Nautical miles

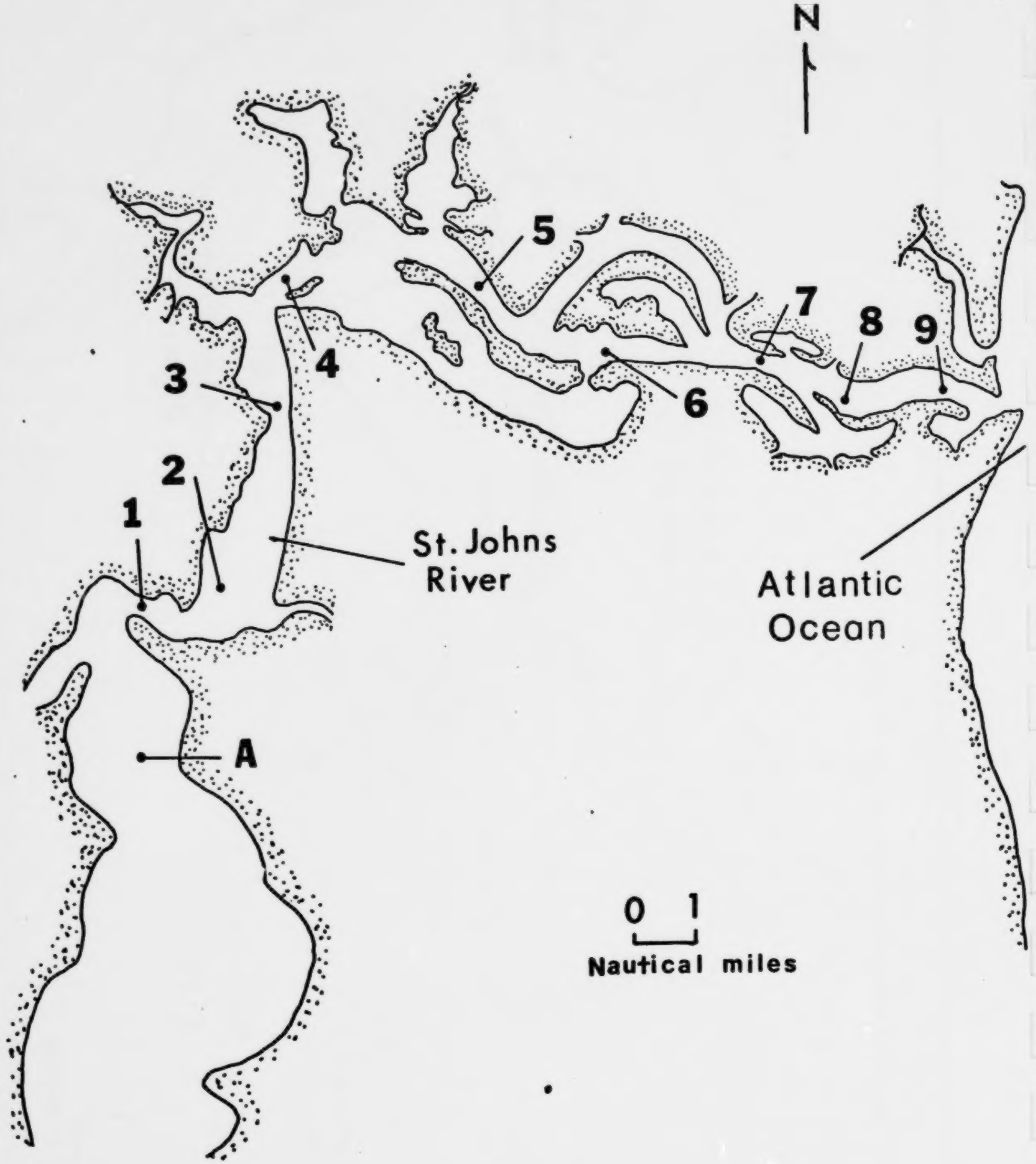

N
5
4
3
2
1
A
6
7
8
9
St. Johns
River
Atlantic
Ocean
0 1
Nautical miles

Figure 9. Sampling station locations on St. Johns River Estuary

can be established. Data for the fresh water parts of the estuaries will allow calculation of the annual discharge of metals by the rivers debauching along the Southeastern Atlantic Coast.

In addition to metal concentrations in the water, other parameters, including salinity, pH, temperature, dissolved oxygen, sulfate, ammonia, nitrate and phosphate concentrations, are also determined at each station. These analyses are done to characterize the chemical system of the river-estuarine area so that processes responsible for changes in metal concentrations might be better understood. The concentrations of the nutrients (ammonia, nitrate and phosphate) give an indication of the levels of municipal wastes being discharged into the estuary. This information in turn may identify the impact of municipal pollution on heavy metal concentrations and provide information about natural levels of nutrients in the rivers and estuaries.

The concentrations of metals in particulate phases of the river water and in bottom and salt marsh sediments are important in elucidating the fate of the metal in the estuarine environment, subsequent to their discharge by rivers. These data, along with data on the rates of sedimentation in salt marshes, indicate the importance of sediments in the coastal area as sinks for the various metals. This information coupled with the total discharge data from the rivers allows the determination of the total flux of metals through the system to the coastal waters.

Water samples for chemical studies were collected using 8 liter niskin samplers fitted with teflon coated springs to prevent metal contamination. Upon collection, samples were immediately filtered through 0.45μ Millipore filters using a nitrogen pressurized PVC filtration system. The filters were cleaned by allowing the first two liters of water to pass and subsequently collecting the water samples in precleaned polypropylene bottles. Before capping the samples 0.5 ml of concentrated ultra pure nitric acid was added to prevent adsorption of metals on the bottle surfaces. The sediment collected on the filter for each sample was stored in petri dishes frozen until analysis. Bottom samples were collected with a PVC corer and also frozen until analyzed. For each station pH, dissolved oxygen and salinity were determined using appropriate probes. Samples for nutrient analyses were collected in small opaque polypropylene bottles and stored frozen until analysis.

Ammonia was determined directly as indophenol blue, using the method of Koroleff (1972). Nitrate was determined by the cadmium reduction method, similar to that described by Strickland and Parsons (1968). Phosphate determination was carried out using the molybdenum blue complex as described by Murphy and Riley (1962). The determination of sulfate was accomplished using a tritation with mecuric acitate of sulfide as described by Johnson and Nischita (1952) and Archer (1956).

All determinations of metals on both water and bottom sediment samples were accomplished using techniques described in Windom and Smith (1972). This manual also describes, in detail, sampling techniques.

Quality control of analyses in our laboratories is maintained by periodic analyses of NBS standards and by participation in intercalibration studies such as the one sponsored by the National Science Foundation (IDOE, 1972) and an opening intercalibration study conducted by Drs. C.C. Patterson and T.J. Chow involving lead analysis of sea water.

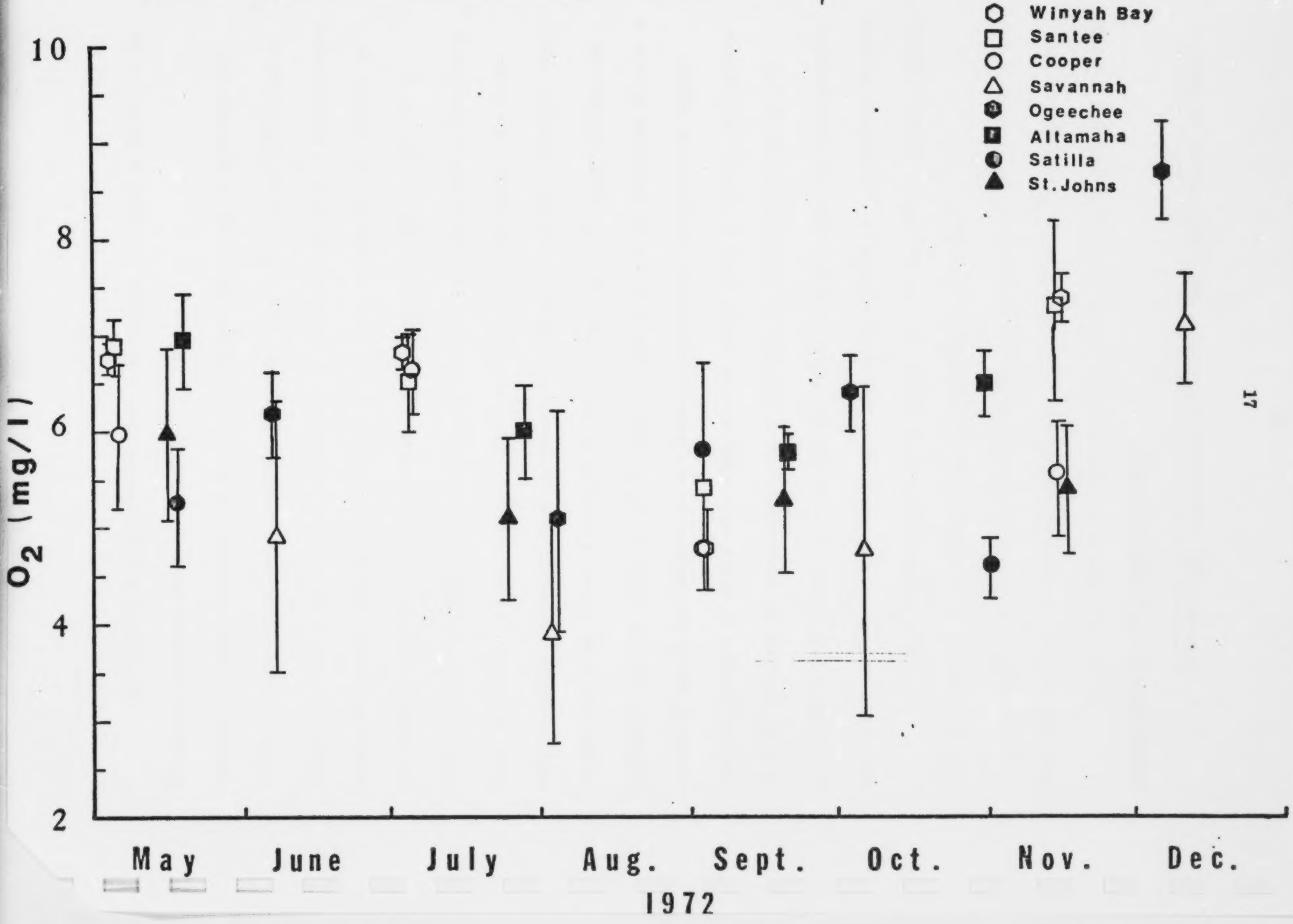
1. Concentrations of Dissolved Oxygen SO_4, NH_4, NO_3 and PO_4 in Southeastern Rivers and Estuarine Waters.

To date only data on samples collected during May through December of 1972 have been reduced so that they may be described here. Samples collected from December,1972,up to May, 1973,have been analyzed for the nutrients, but results of these were not available in a reduced form to be included in the report.

For the purposes of the present report, the data for oxygen, sulfate, ammonia, nitrate and phosphate are summarized in Figures 10 through 14. In Figure 10 the data for oxygen concentrations in the rivers and estuaries of the study area are combined showing the range for each estuary (fresh water to salt water). As can be seen,a marked variation in oxygen concentrations with season takes place with the minimum occurring during the summer due to elevated temperatures and decreased oxygen solubility. Also,the range in oxygen concentrations in each of the estuaries appears to be less during the winter than during summer months. It is interesting to point out that the oxygen concentrations in all the estuaries studied, whether polluted or unpolluted, appeared to be quite similar. This probably reflects the affect of the large concentrations of organic matter being transported by all of these rivers giving each a similar fairly large oxygen demanding capacity which overshadows that due to industrial wastes. This is not to say that certain parts of these rivers, such as the industrial areas of the Savannah, Cooper and St. Johns Rivers do not have depressed oxygen concentrations due to industrial activities. The large natural oxygen deficit observed for these estuaries is characteristic of the region and has been reported previously (Windom and Beck, 1971).

The data for sulfate concentrations with salinity are shown in Figure 11 for

Figure 10. Variations in Dissolved Oxygen in Southeastern Estuaries



all the areas studied, since they all show a similar trend of increasing sulfate due to mixing with sulfate rich marine waters. The range in sulfate concentrations of the river waters shown as the range in concentrations of sulfate at 0 salinity is quite large going from less than 10 ppm up to as high as 400 ppm. The sulfate determinations made on these waters probably include some sulfur compounds discharged by the various pulp mills common to many of the rivers in this region. This may account for some of the higher values of sulfate above a normally expected range around 10 ppm (Livingstone, 1963). Similar high values of sulfate in coastal waters receiving effluents from pulp mills have been observed by Windom (1971).

Ammonia levels appear to show a seasonal trend with increasing concentrations during the summer (Figure 12). Generally, the ammonia levels in polluted rivers do not show any significantly increased values over unpolluted rivers. Nitrate and phosphate, however, (Figres 13 and 14) do show some increase in concentration in the industrialized rivers of the area. For example, samples from Winyah Bay, the Savannah and St. Johns Rivers show levels higher than those of the other rivers. Consistently high levels of phosphate in the St. Johns River may reflect, inpart, the high concentrations of phosphate deposits in its drainage basin. No seasonal trend in nitrate and phosphate appears to occur.

On the basis of the concentrations of oxygen, sulfate, ammonia, nitrate and phosphate, the differences in the rivers of the areas studied appear to be small. The small changes that are observed, are most likely due to municipal wastes, discharges from paper mills and possibly, in the case of the St. Johns River, significant differences in the characteristics of drainage basins.

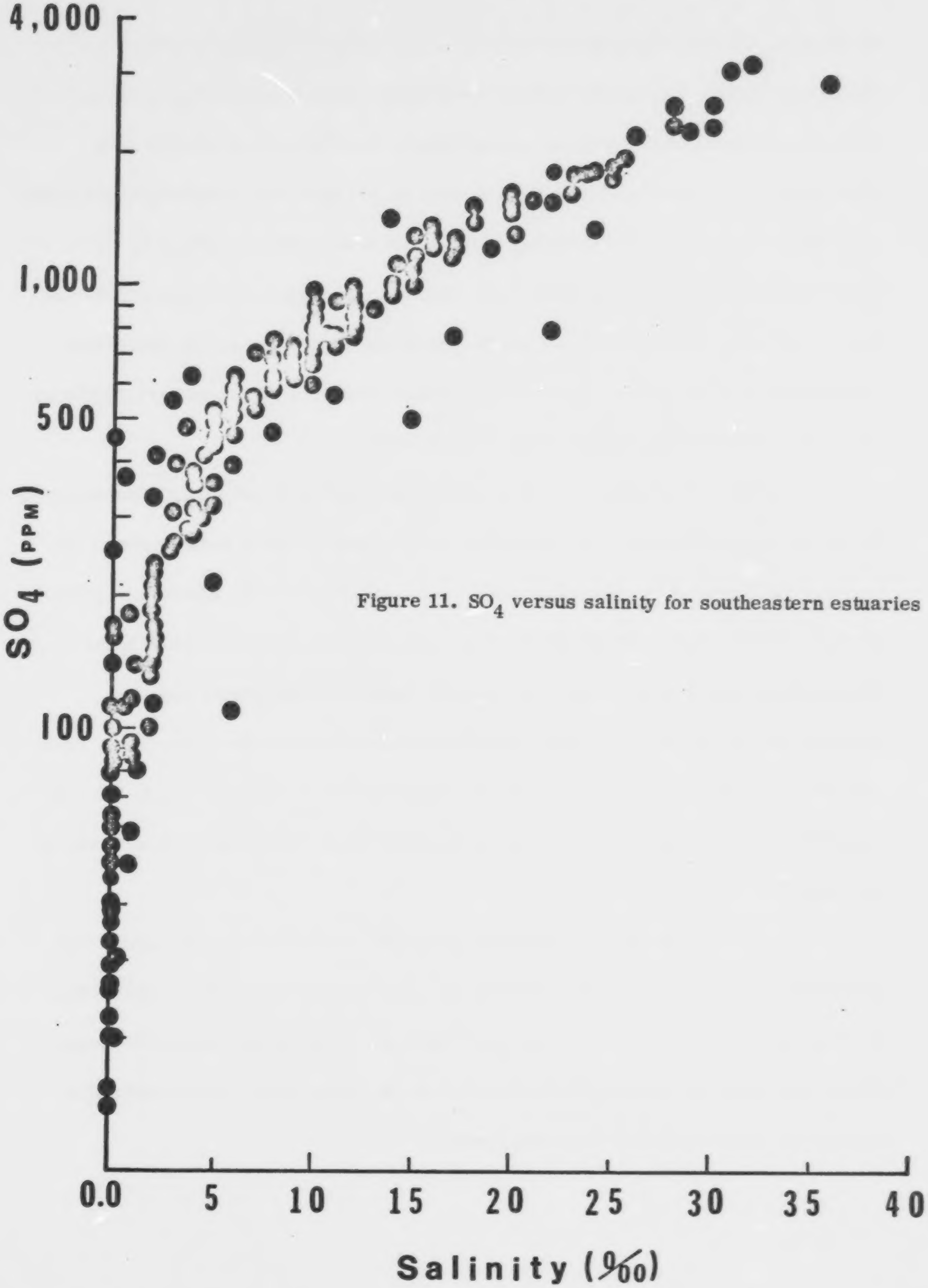


Figure 11. SO_4 versus salinity for southeastern estuaries

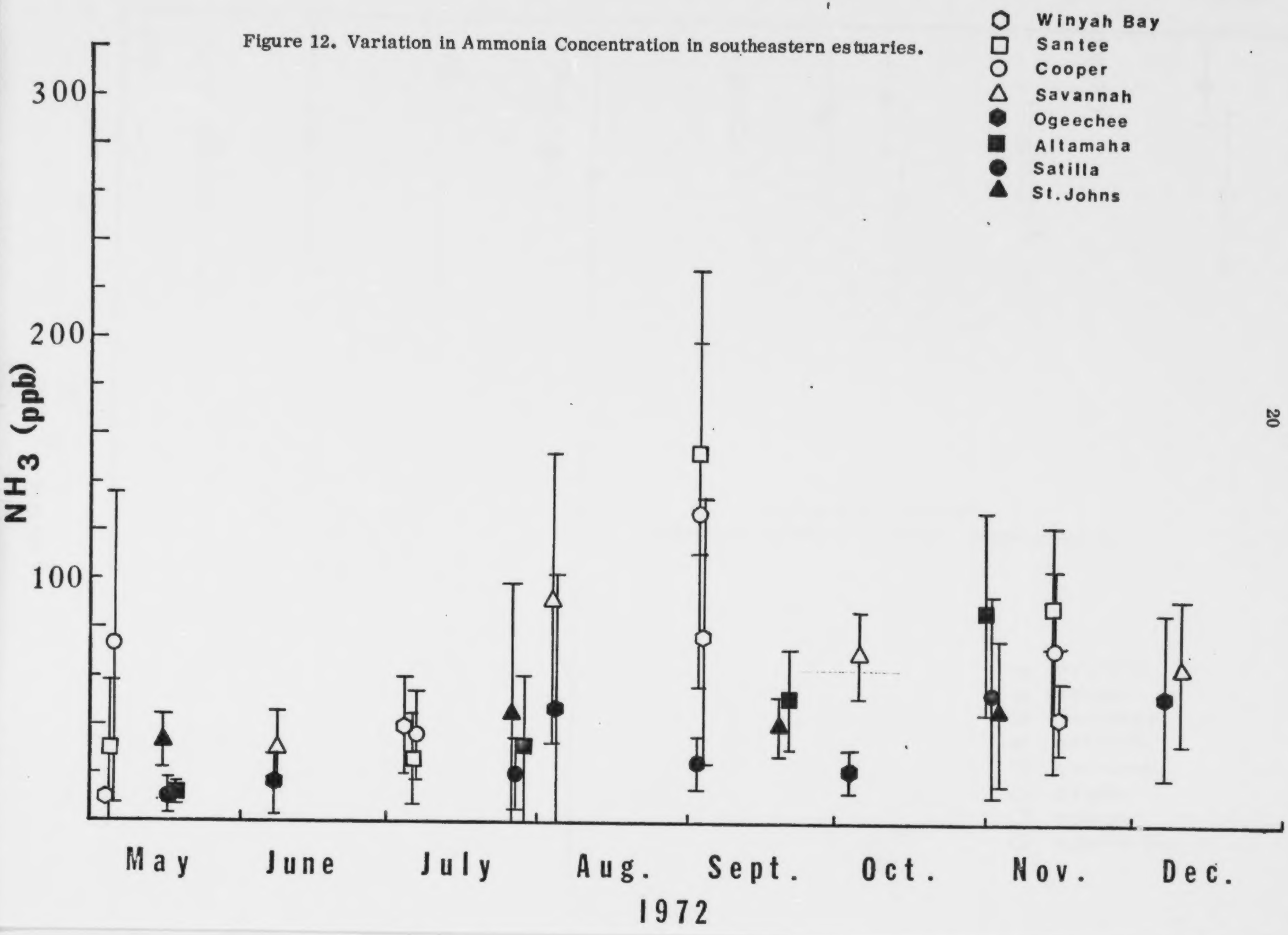


Figure 12. Variation in Ammonia Concentration in southeastern estuaries.

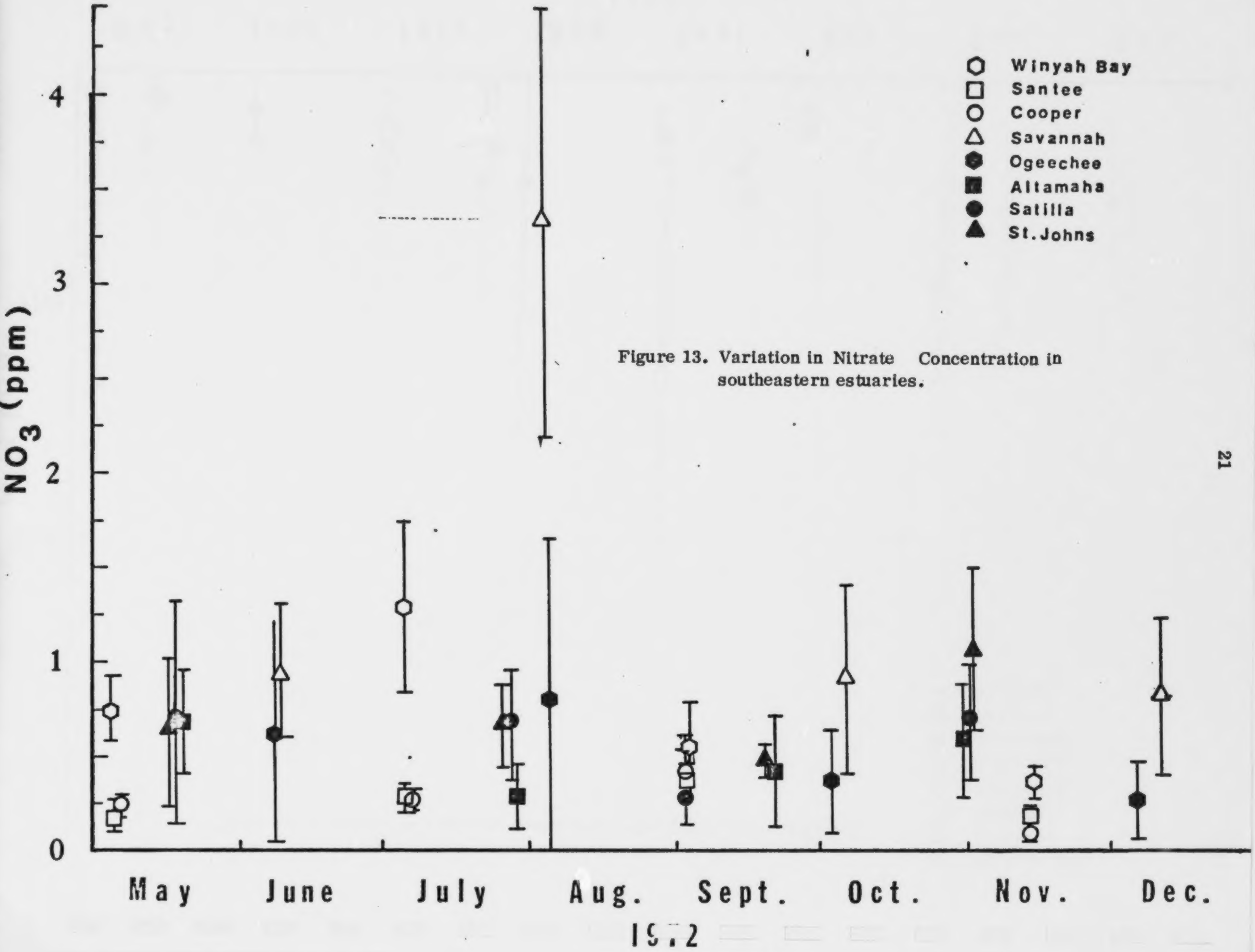


Figure 13. Variation in Nitrate Concentration in southeastern estuaries.

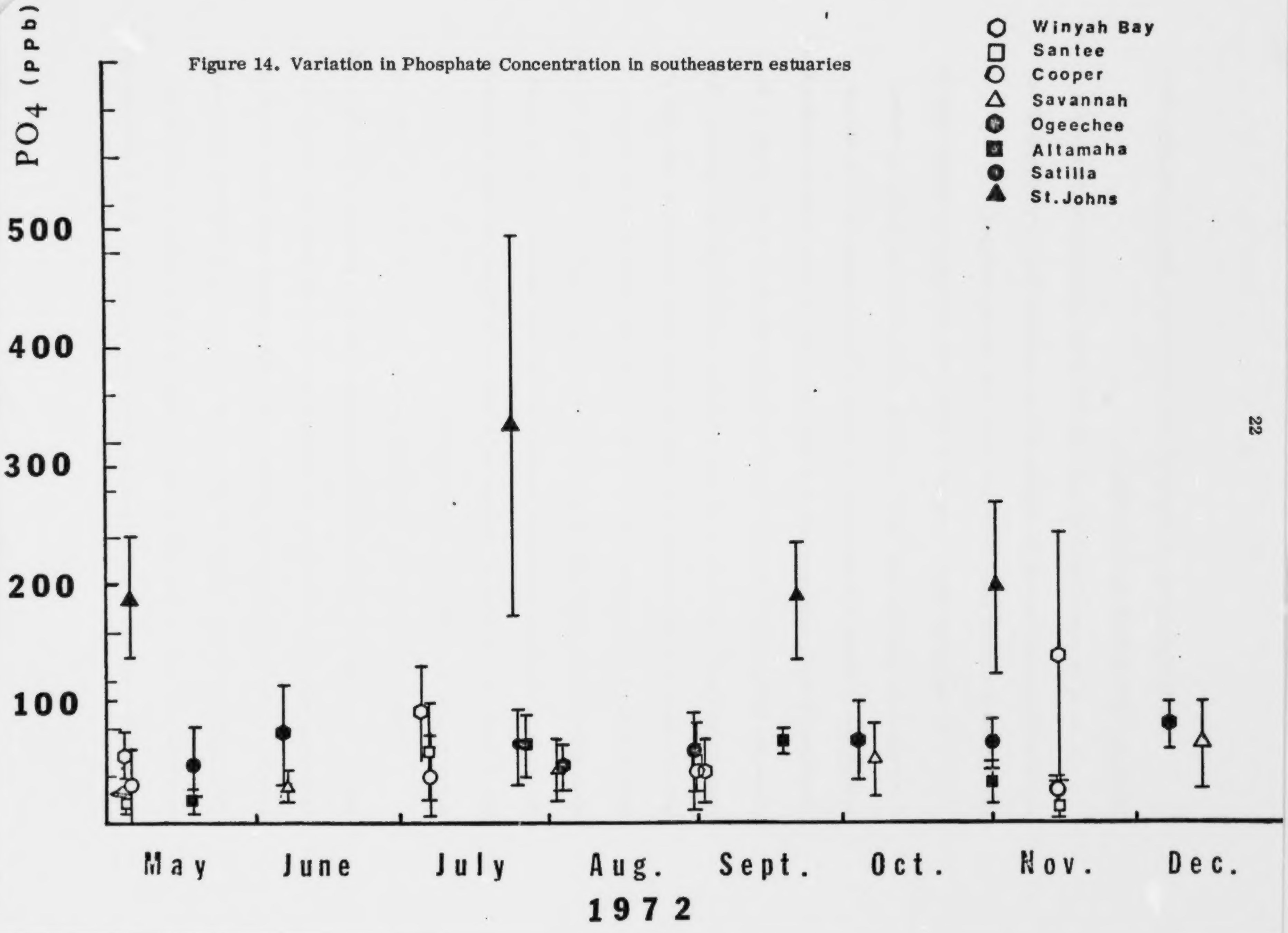


Figure 14. Variation in Phosphate Concentration in southeastern estuaries

2. Concentrations of Dissolved Iron, Manganese, Copper, Mercury, Cadmium and Lead in Southeastern Estuaries.

As in the case of nutrient, only data for metal concentrations in samples collected during May through December 1973 are reported here, even though all but the last set of samples (May 1973) have been collected and analyzed.

As was stated above, samples collected from the estuaries studied (Figures 2 through 9) included the fresh water discharge of the rivers and waters of various salinity due to mixing with sea water. Analyses of these samples serve to indicate variations in metal concentrations with salinities. This, in turn, reflects geochemical processes taking place at the salt water-fresh water interface, as the metals in the fresh water runoff equilibrate to the new conditions of the marine environment. The net difference in metal concentrations between fresh water and marine water can be seen from the data in Tables 1 and 2. In the case of iron, manganese and copper, clear differences are evident, while the concentrations of mercury, cadmium and lead appear to be relatively unchanged. Mercury is a possible exception in the Savannah River where its concentration appears to be significantly higher than that of the more saline regions of the Savannah River estuary.

The variations in iron and manganese with salinity are shown in Figures 15 and 16. An exponential decrease in both manganese and iron appears to take place with increasing salinities, suggesting that the changes in iron and manganese are due to processes other than mixing with marine waters which contain much lower levels of these metals (Table 2). Figure 17 and 18 show the variations of iron and manganese as a function of pH. On the basis of this relationship it is tempting to attribute the decrease of these metals to the precipitation of their hydroxides. This is probably not

TABLE 1

Mean Concentrations of Metals in Solution in Southeastern Rivers During May Through December 1972

River	μg/l					
	Fe	Mn	Cu	Hg	Cd	Pb
Pee Dee	175	25	7.4	0.06	1.0	2.4
Black	198	25	9.0	0.08	1.5	2.1
Santee	71	6.3	3.2	0.05	0.4	2.2
Cooper	16	4.5	4.2	0.04	1.0	1.6
Savannah	92	18	4.1	0.10	0.5	2.7
Ogeechee	226	32	6.6	0.10	1.3	3.5
Altamaha	106	6.8	4.6	0.05	1.1	1.7
Satilla	440	51	4.0	0.10	0.9	2.0
St. Johns	56	3.9	4.9	0.05	0.7	2.6

TABLE 2

Mean Concentrations of Metals in Solution in Southeastern Estuaries
During May Through December 1972

Estuary	$\mu g/l$					
	Fe	Mn	Cu	Hg	Cd	Pb
Winyah	55	18	3.4	0.07	1.0	2.5
Santee	10	17	4.0	0.06	0.7	2.7
Cooper	10	65	3.5	0.08	1.3	1.9
Savannah	16	51	3.4	0.22	0.8	1.9
Ogeechee	18	5.2	2.5	0.10	0.4	1.4
Altamaha	11	4.1	3.3	0.06	2.4	2.9
Satilla	28	7.4	3.1	0.07	0.9	2.1
St. Johns	28	6.5	3.2	0.05	1.4	2.5

Figure 15. Variation in iron concentration with salinity.

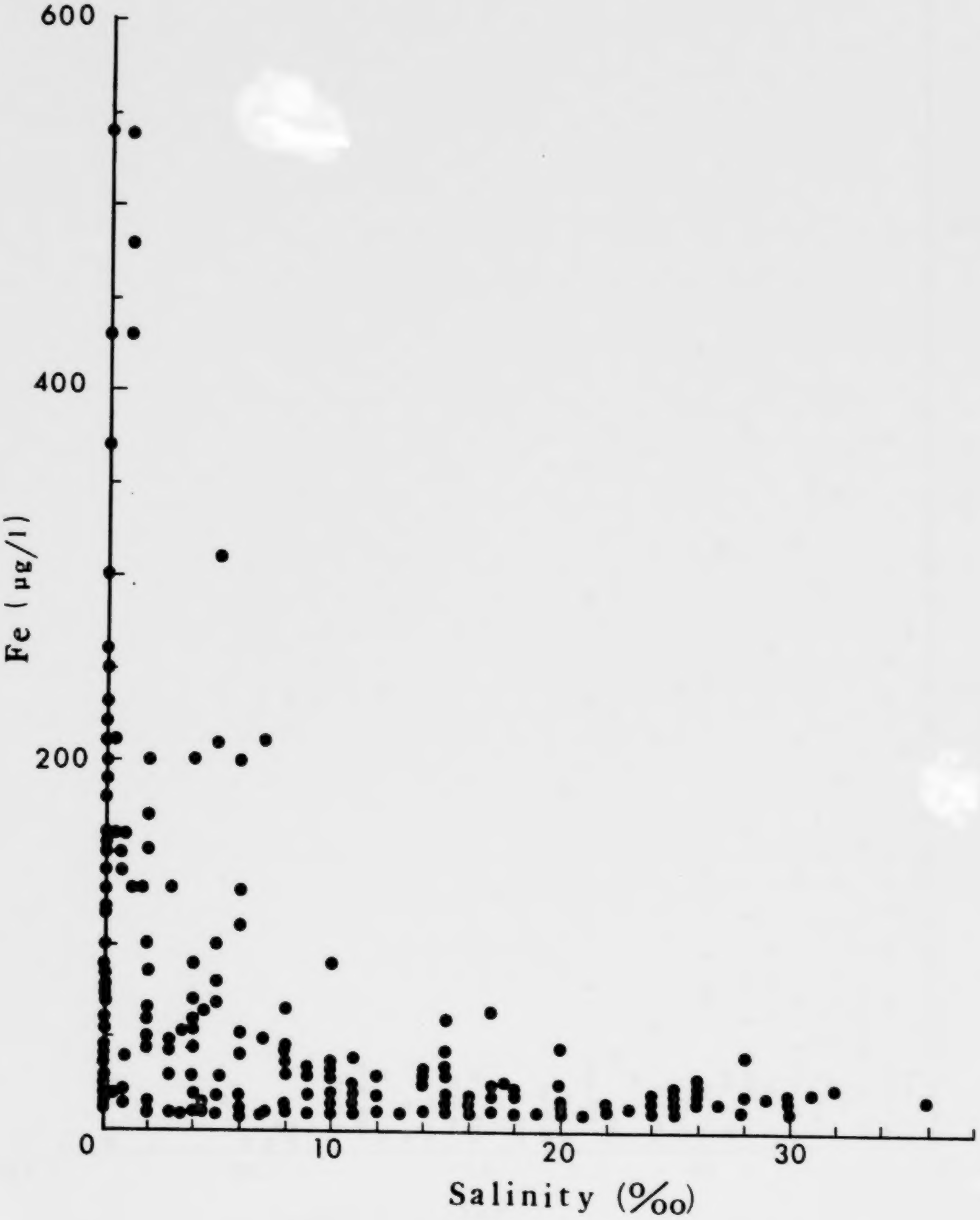


Figure 16. Variation in manganese with salinity.

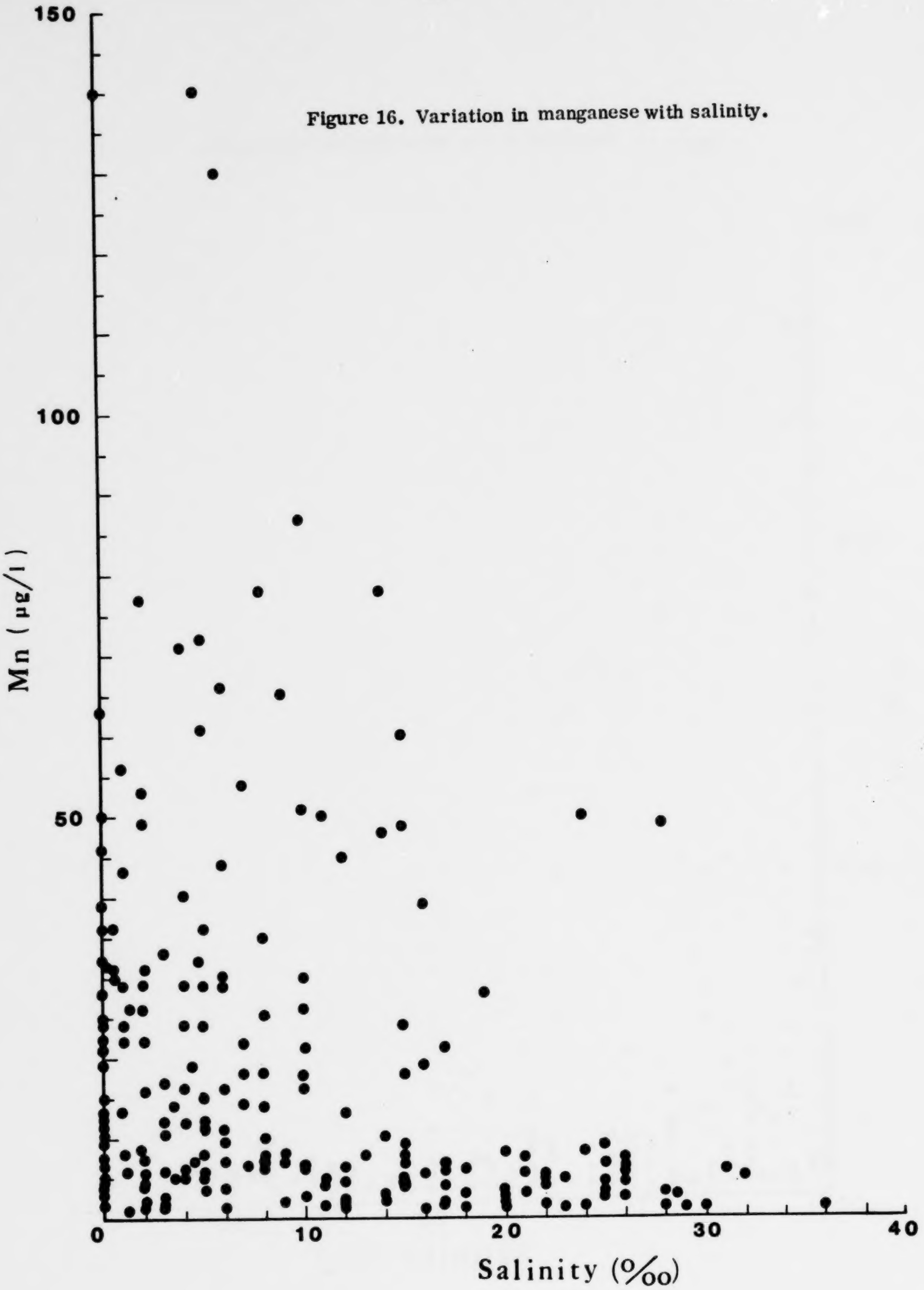


Figure 17. Variations in iron with pH.

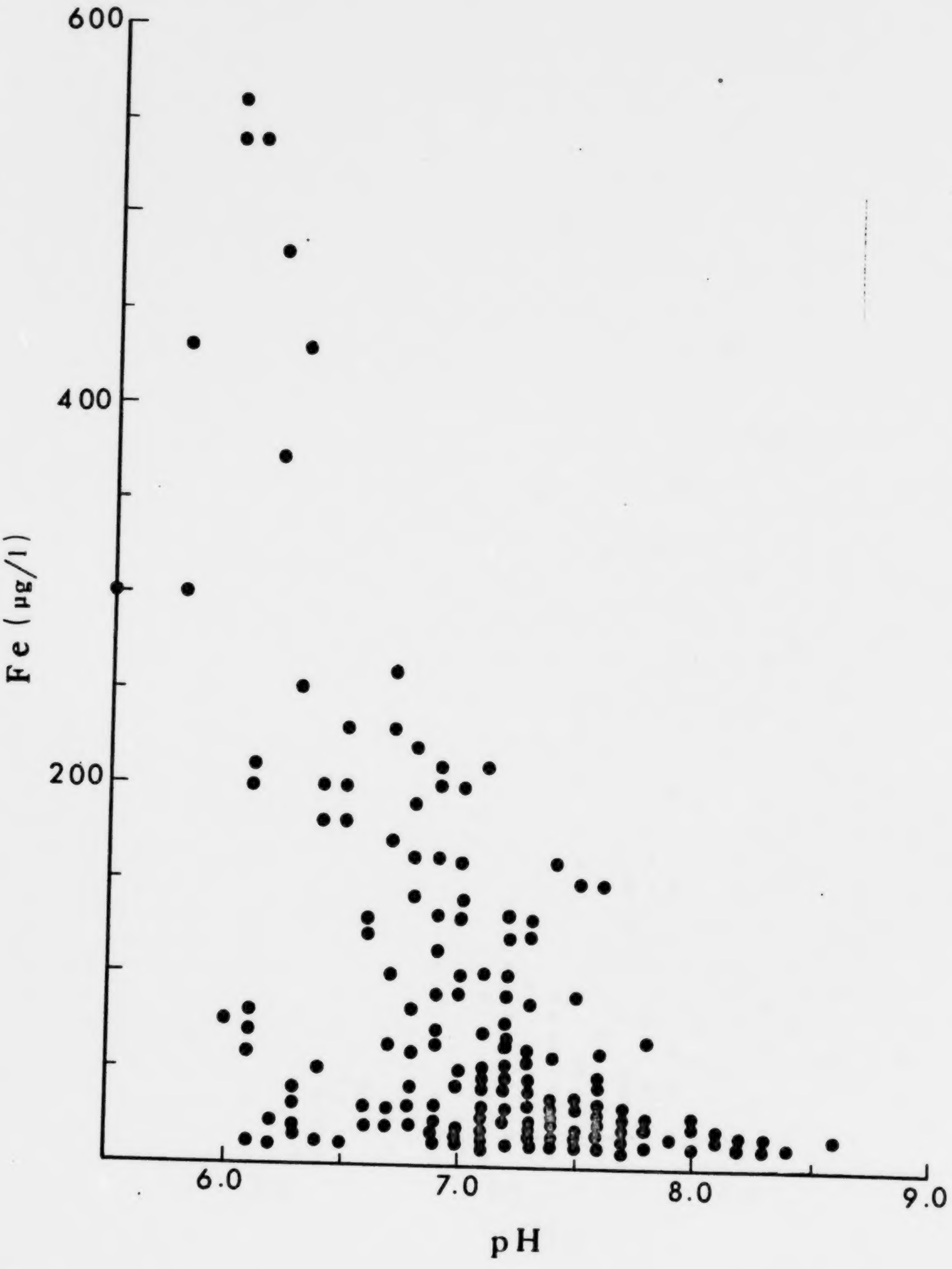
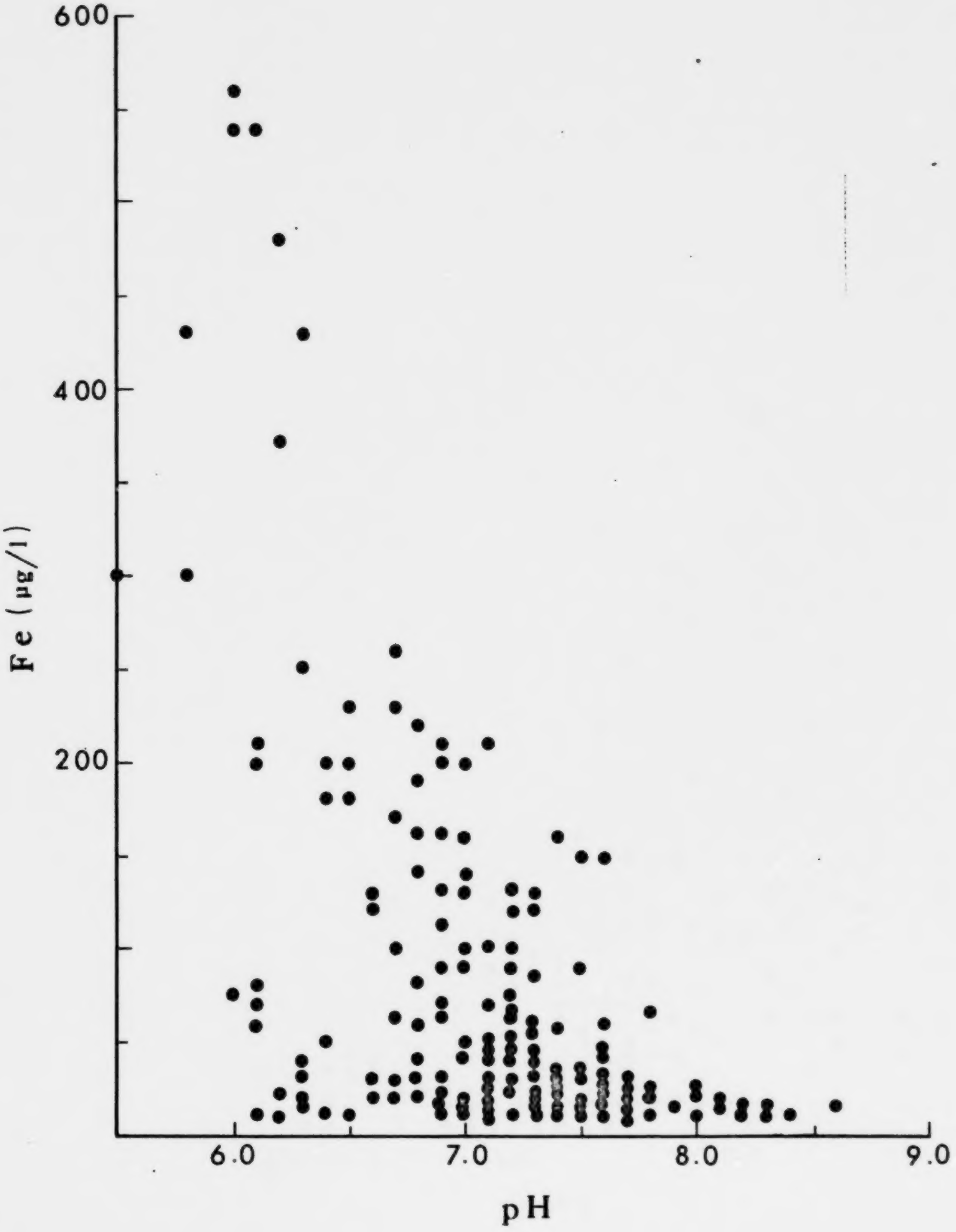


Figure 17. Variations in iron with pH.



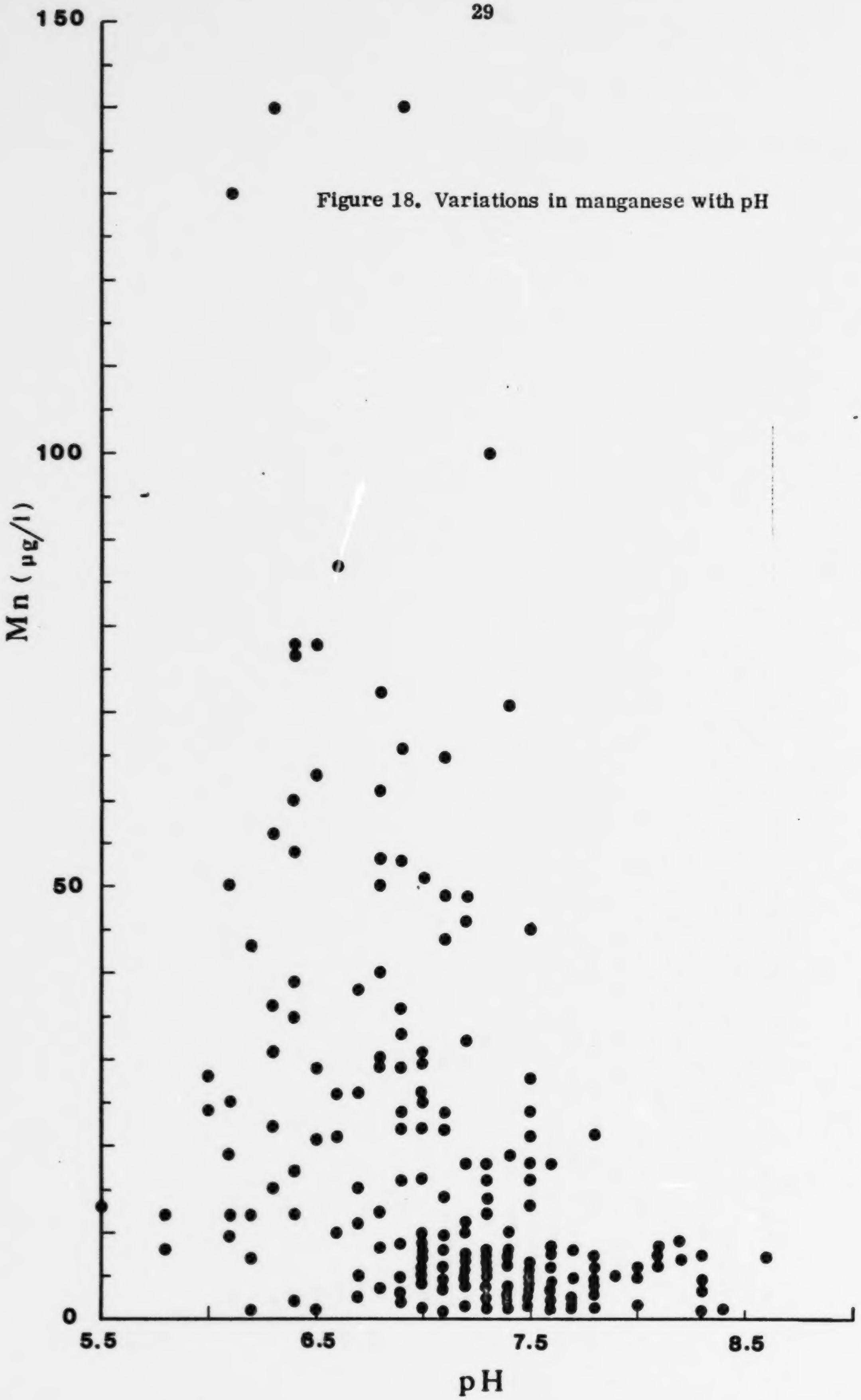


Figure 18. Variations in manganese with pH

totally the case, however, since both iron and manganese occur in the fresh water parts of the rivers where pH is relatively low at levels higher than their solubilities relative to hydroxides. At the Eh of the river waters under study reported by Windom et al. (1971) a large portion of the solubilized iron may occur in the +2 state. At this valence its solubility may approach the levels observed and the decrease in iron concentration may be due, in large part, to the precipitation of iron hydroxide. Manganese, however, under these conditions should be in the +4 state having a very low solubility relative to manganic oxide. It is quite probable that a good part of the manganese and a portion of the iron occur in the water column as fine colloidal particles which pass the 0.45μ filter. Upon entry into the more saline waters floculations of the colloidal material may be a prime cause of the decrease in the concentrations of these metals. Much of the metals may also occur as organic complexes.

Regardless of the mechanism of decrease in the concentrations of iron and manganese the precipitation of compounds of these elements at low salinities may be extremely important to the fate of other metals. For example iron hydroxides have been found to be an efficient scavenger of other metals such as copper (Krauskopf, 1956). This may explain the decrease in concentrations of copper going from fresh water to marine waters. Hydroxides of iron have also been shown to be efficient scavengers of organic molecules (Sridharan and Lee, 1972) and may preferentially affect the concentration of organic complexes of metals.

The supply of iron and manganese by the various rivers varies considerably from river to river. Factors controlling the variations of these two metals, however, appear to be similar since iron and manganese concentrations in river waters are clearly related as shown in Figure 19. The line drawn in this Figure is a linear re-

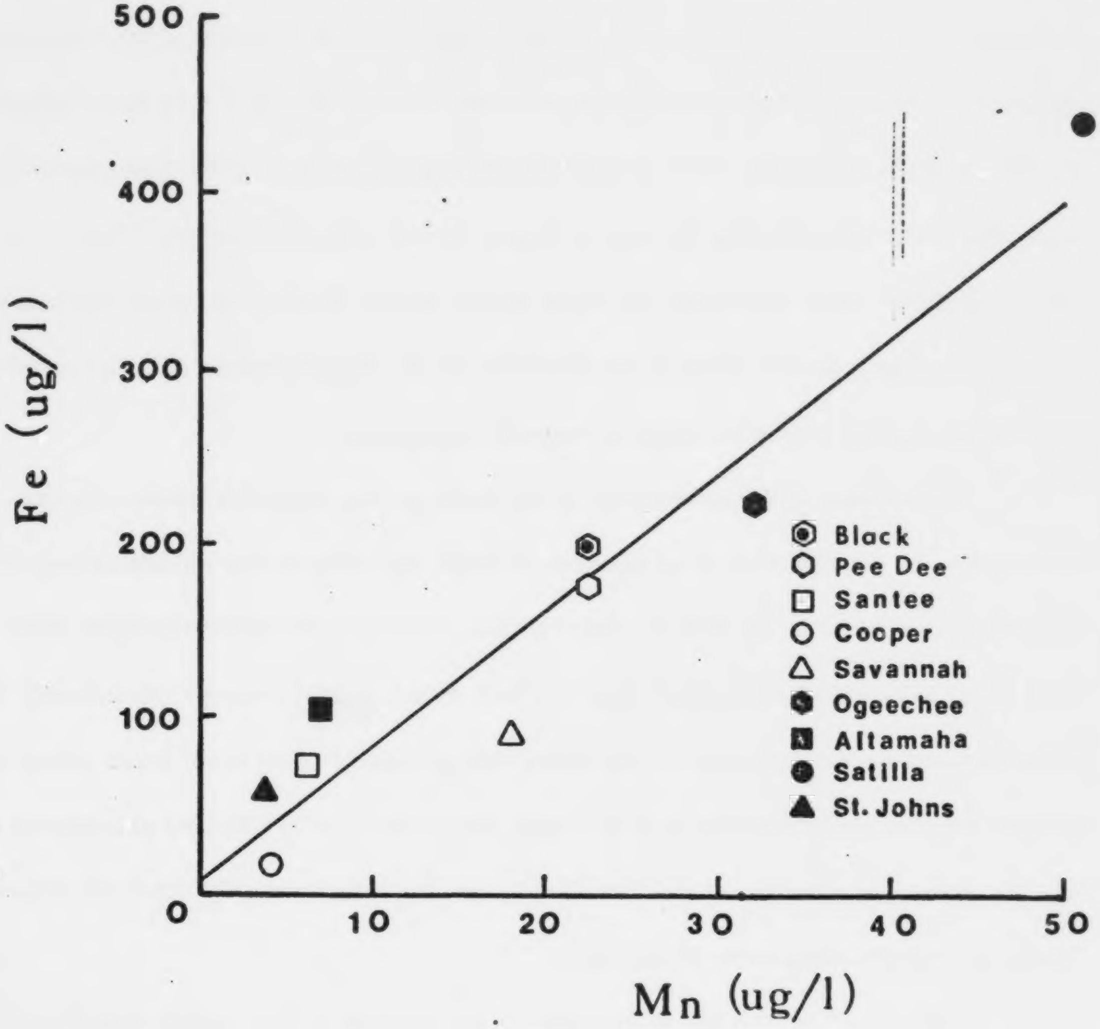


Figure 19. Iron versus manganese in southeastern river waters. Regression curve follows the general equation: Fe = 7.8 Mn+ 4. (each point represents an average concentration for mercury and iron in each estuary).

gression curve having a coefficient of correlation of 0.06. The control of iron and manganese concentrations in river waters is probably influenced by the amount of organic ligands available for complexation. This supports the hypothesis that these metals are probably in solution as organic colloids or possibly organic complexes which flocculate or precipitate at the fresh water-salt water interface.

No significant variation in the concentration of iron and manganese with time of year was observed. This is also true of copper and lead as shown in Figures 20 and 21. This may reflect control of these metals by flocculation or precipitation of hydrated ferro-manganese oxides. Cadmium and mercury on the other hand (Figures 22 and 23) show a tendency toward seasonal changes in their concentrations. In the case of cadmium, higher concentrations are observed during the late fall and early winter. Mercury also shows seasonal patterns in the estuaries with a minimum around September and October. Occurrence of seasonal patterns of mercury in coastal waters is also apparent based on the data shown in Figure 24. Here the influence of the discharges from the Savannah River on coastal waters is clearly obvious. The seasonal variations in these metals may be due in part to seasonal variations in runoffs, which are minimum during September and October for southeastern Atlantic rivers.

3. Concentrations of Particulate Iron, Manganese, Copper, Mercury Cadmium, Lead and Zinc in Southeastern Estuarine Waters.

Concentrations of metals in particulate matter of river waters as opposed to that of more saline estuarine waters, are of interest in that they suggest whether metals are released or adsorbed by particulate phases on transport into the marine environment. For this reason concentrations of particulate matter filtered from water samples

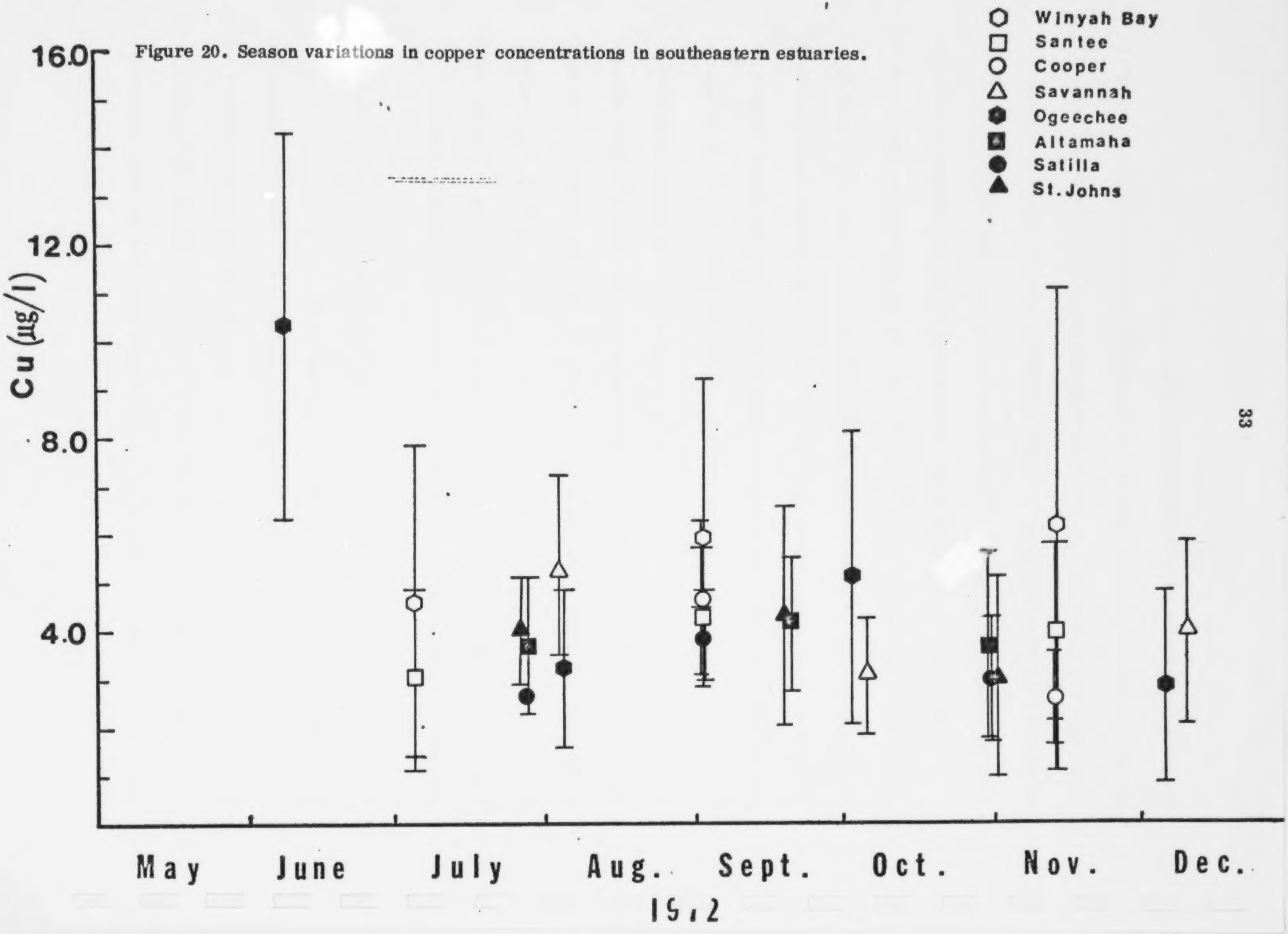


Figure 20. Season variations in copper concentrations in southeastern estuaries.

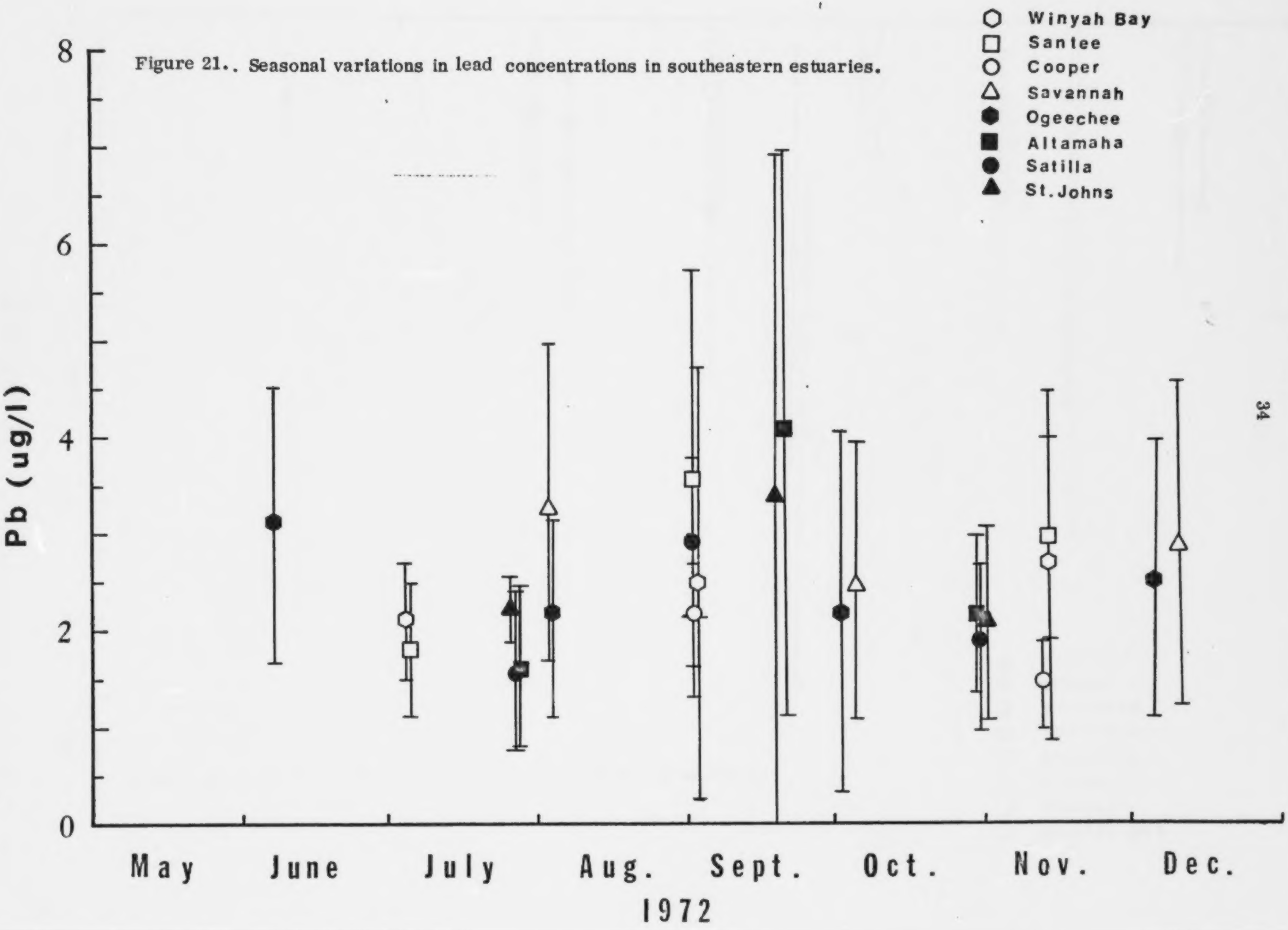


Figure 21.. Seasonal variations in lead concentrations in southeastern estuaries.

Figure 22. Seasonal variations in cadmium in southeastern estuaries.

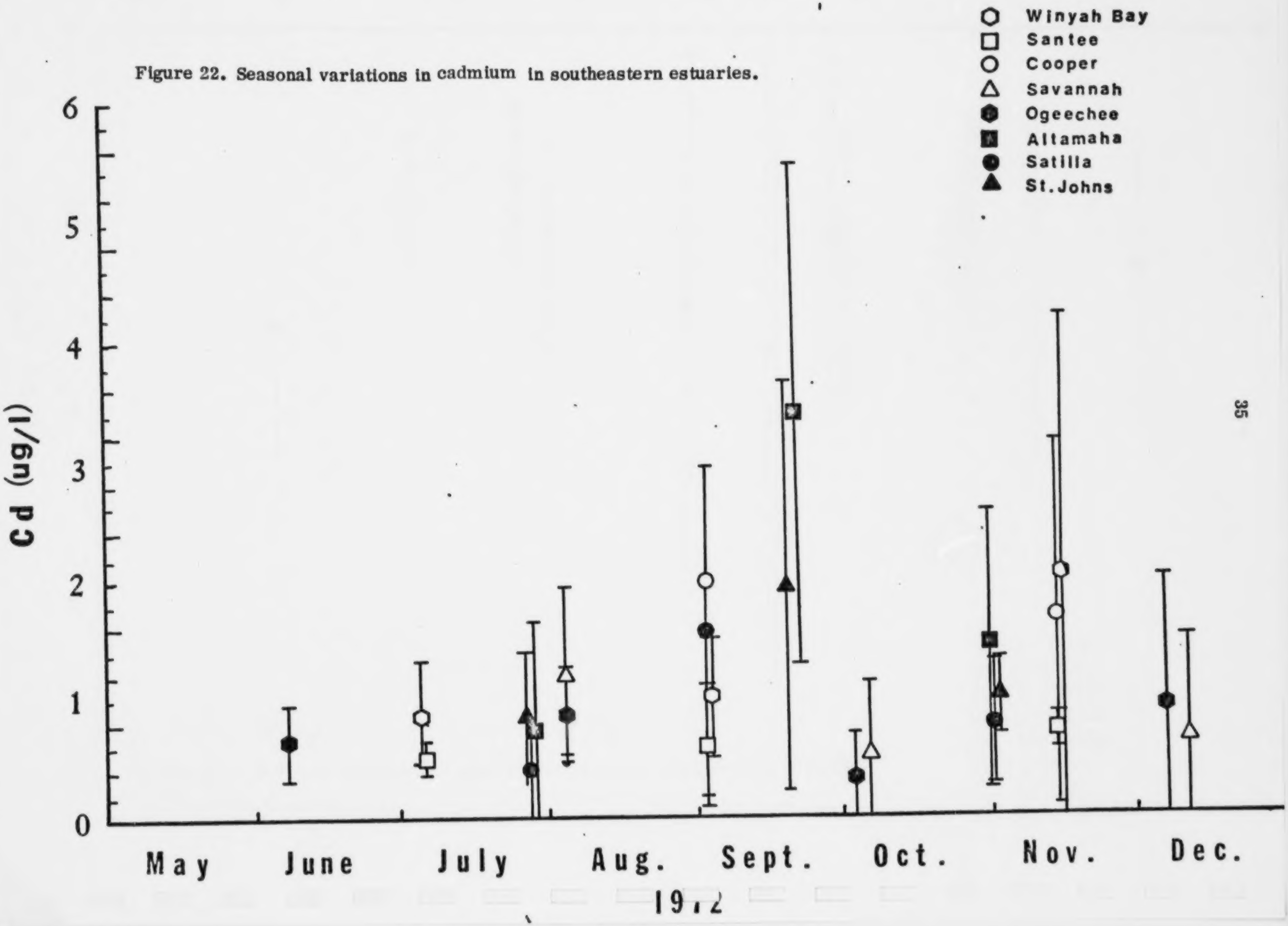
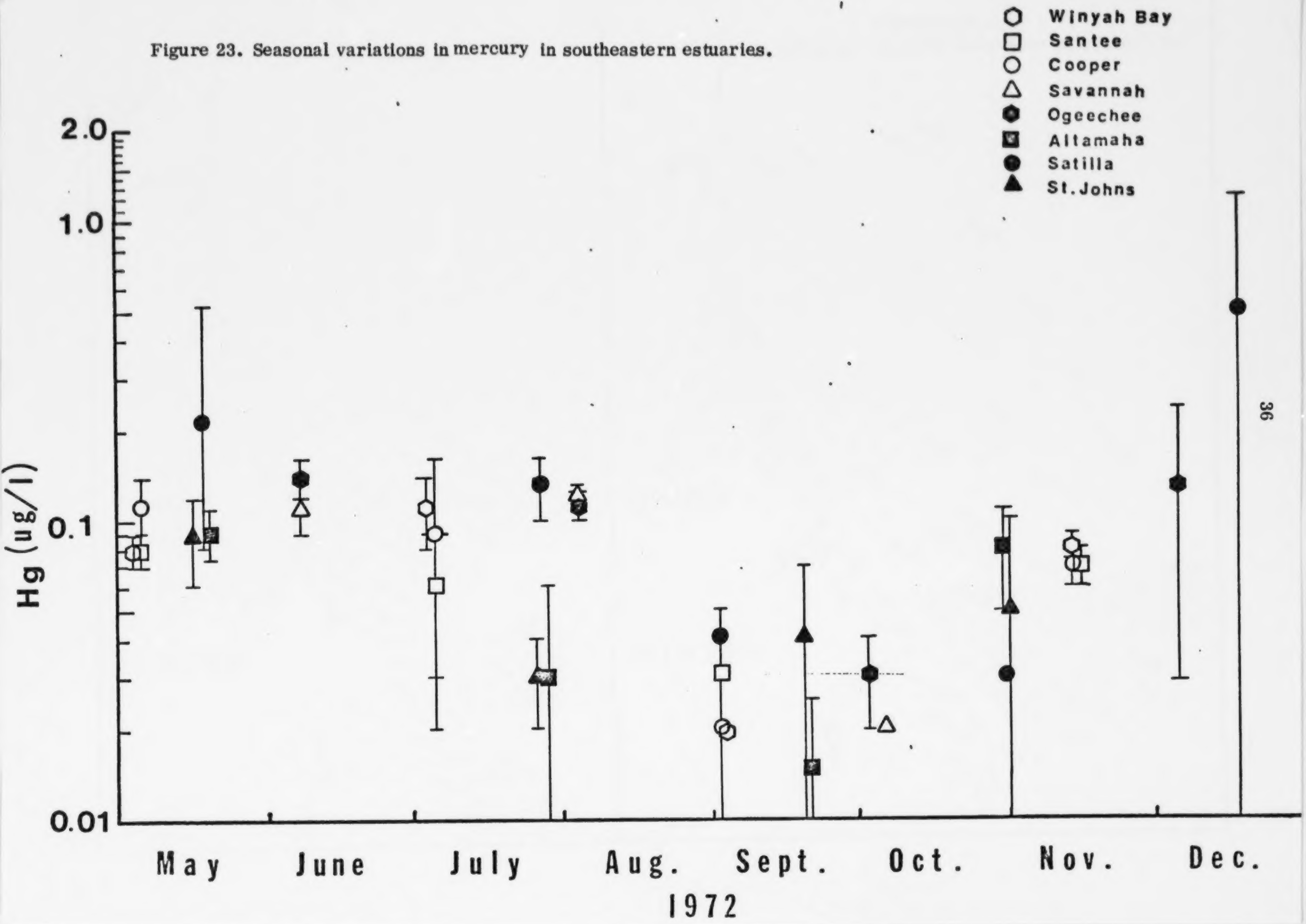
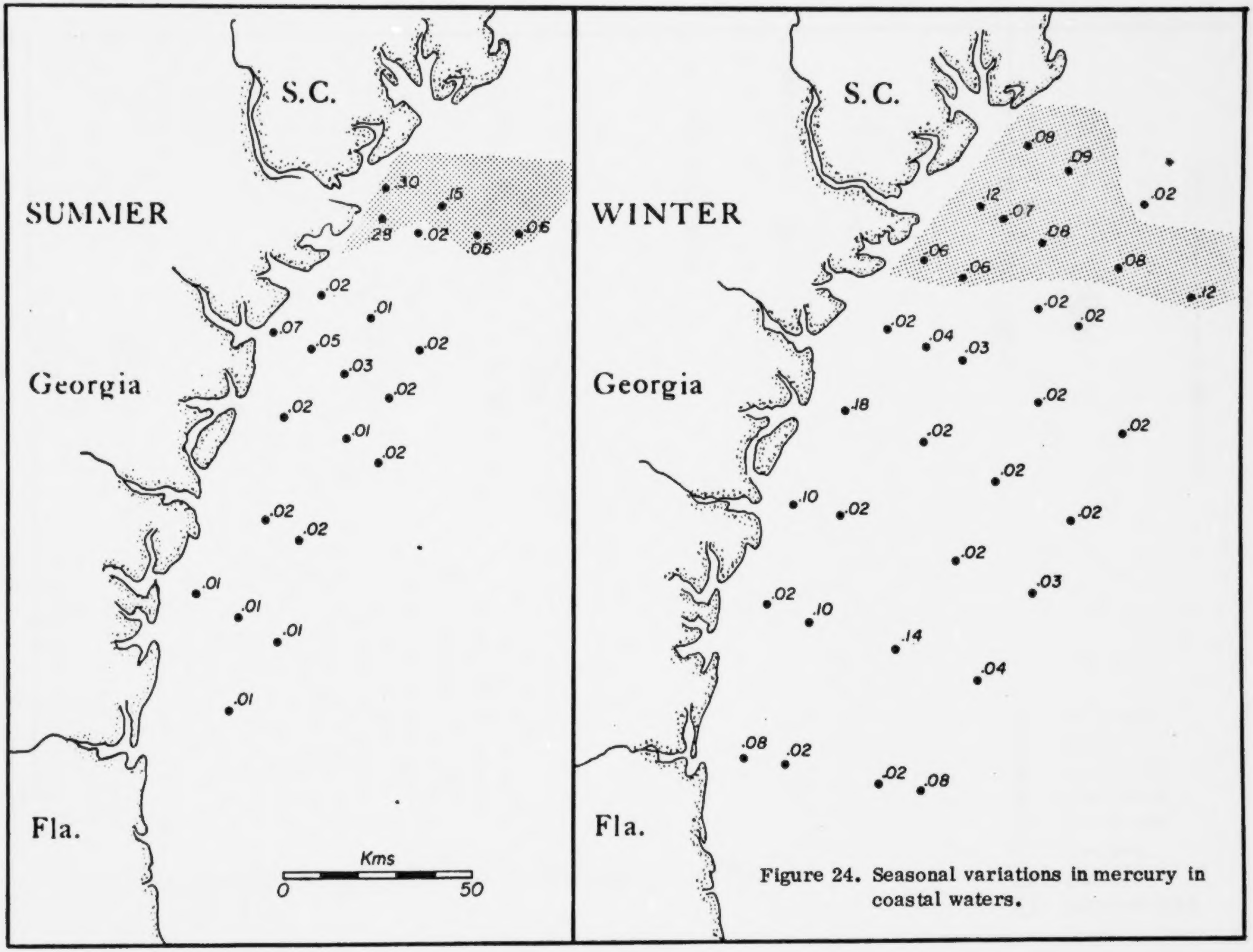


Figure 23. Seasonal variations in mercury in southeastern estuaries.

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WINTER
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Figure 24. Seasonal variations in mercury in coastal waters.

collected at the stations of each of the rivers studied were analyzed. Results of samples collected in the fresh water areas are separated from those collected in saline waters and shown in Tables 3 and 4. These data have been graphically presented in Figures 25 through 33, so that the relative concentrations of metals in particulate matter in river water can be compared to that in estuarine waters of the various estuaries. Iron and zinc concentrations in suspended sediments are similar in both the fresh water and saline parts of each of the estuaries. This is observed in Figures 25 and 26 as a cluster of points along the curve shown which has a 1 to 1 slope.

Figure 27 and 28 show a rather random scatter of mercury and cadmium particulate concentrations in river water versus estuarine waters. These data do not suggest either adsorption or desorption of these metals by suspended sediments. The variability in the concentrations of the metals in the particulate phases are more probably due to factors other than changes in the salinity.

The relationship between lead concentrations in particulate matter of fresh water as compared to that of particulate matter in saline waters of the same estuary indicates a tendecy toward higher concentrations in particulate phases of river runoff, with a decrease in concentration in the saline areas. These data suggest the possibility of desorption reactions leading to the decrease in lead in the particulate matter of saline regions of the estuaries.

Copper (Figure 30) also appears to be increased in concentration in particulate matter of rivers as compared to marine waters. This again suggests the possibility of desorption upon entry into saline waters. Data presented in Figures 31, however, indicate that the total organic carbon is also higher in particulate matter of rivers and may be the controlling influence on the copper and lead distribution in the particulate

TABLE 3

Average Total Metal Concentration in Suspended Sediment of Southeastern Atlantic Rivers*

Estuary	mg/l Suspended Solids	TOC %	Fe %	µg/g					
				Mn	Cu	Hg	Cd	Pb	Zn
Pee Dee	9	6.8	6.6	1200	67	1.3	7	130	890
Black	12	8.1	6.5	1400	76	1.7	11	120	610
Santee	78	4.1	6.0	1300	39	0.6	4	51	390
Cooper	6	8.4	3.4	1020	96	0.8	27	72	970
Savannah	28	3.4	5.9	1670	92	0.8	3	62	350
Ogeechee	6	10.8	4.2	450	90	1.5	15	110	320
Altamaha	16	8.2	5.0	2640	83	1.1	28	94	690
Satilla	18	6.4	5.0	340	45	0.2	19	99	160
St. Johns	11	11.4	3.9	650	106	0.7	13	120	590

* Average based on results of analyses of samples from sampling stations with salinities less than 1‰ during May, July and September, 1972.

TABLE 4

Average Total Metal Concentration in Suspended Sediment of Southeastern Atlantic Estuaries*

Estuary	mg/l Suspended Solids	TOC %	Fe %	µg/g Mn	Cu	Hg	Cd	Pb	Zn
Winyah Bay	19	4.7	5.8	730	81	1.0	14	59	510
Santee	51	4.2	5.3	1100	36	0.4	6	48	190
Cooper	11	5.7	8.7	1150	77	1.5	6	110	1100
Savannah	16	4.5	5.0	580	76	1.2	9	140	260
Ogeechee	35	4.4	4.0	2050	70	0.7	8	69	290
Altamaha	46	4.6	4.0	1640	45	0.6	9	47	660
Satilla	70	2.7	5.6	950	24	0.6	5	43	180
St. Johns	9	7.7	2.9	500	80	1.0	18	119	620

* Averages based on samples collected from sampling stations with salinities greater than 1‰ during May, July and September, 1972.

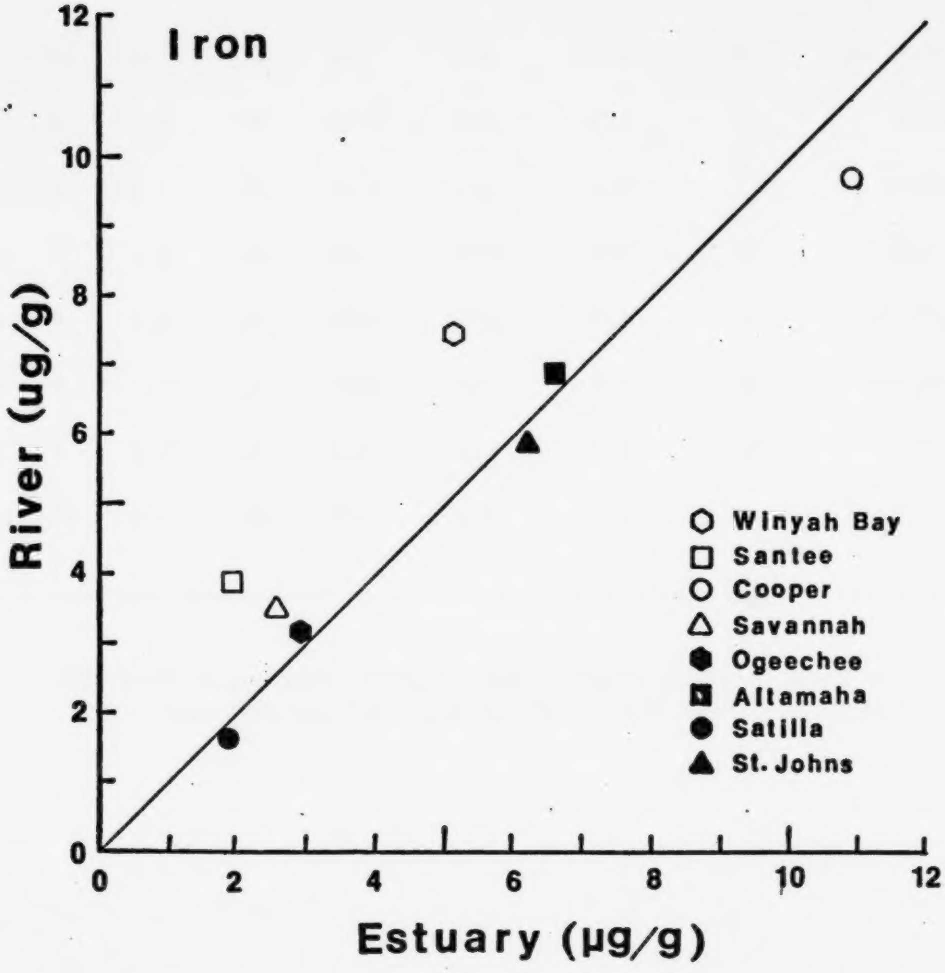

Figure 25. Iron in particulate matter of river versus that of estuarine water.

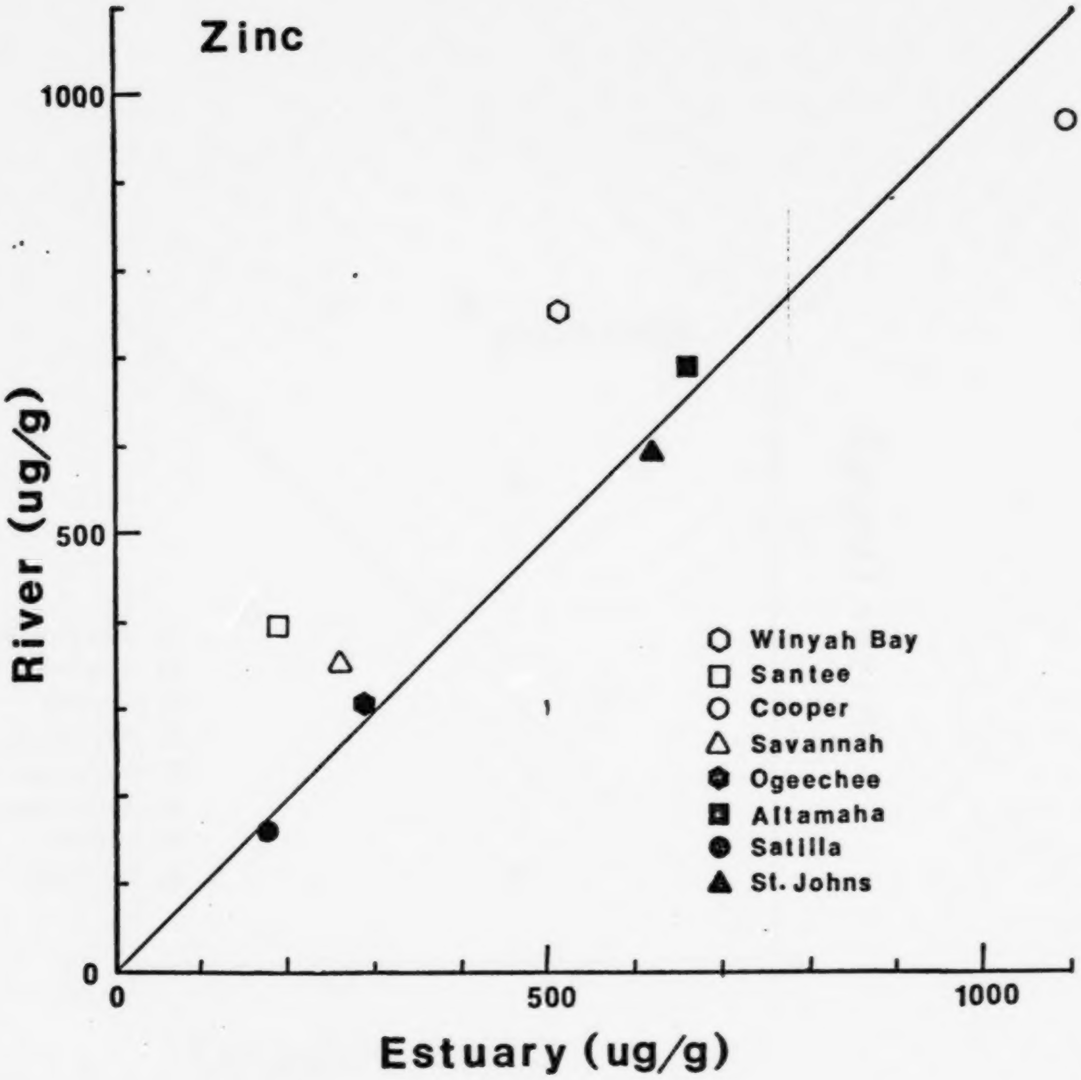

Figure 26. Zinc in particulate matter of river versus that of estuarine water.

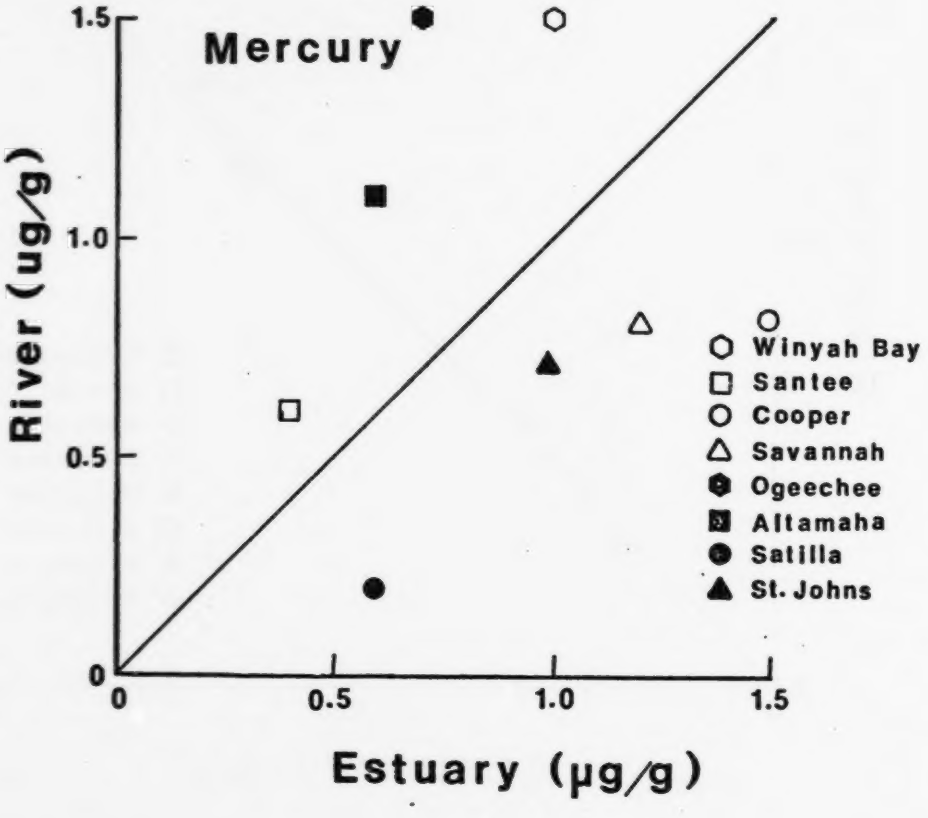

Figure 27. Mercury in particulate matter of river versus that of estuarine water.

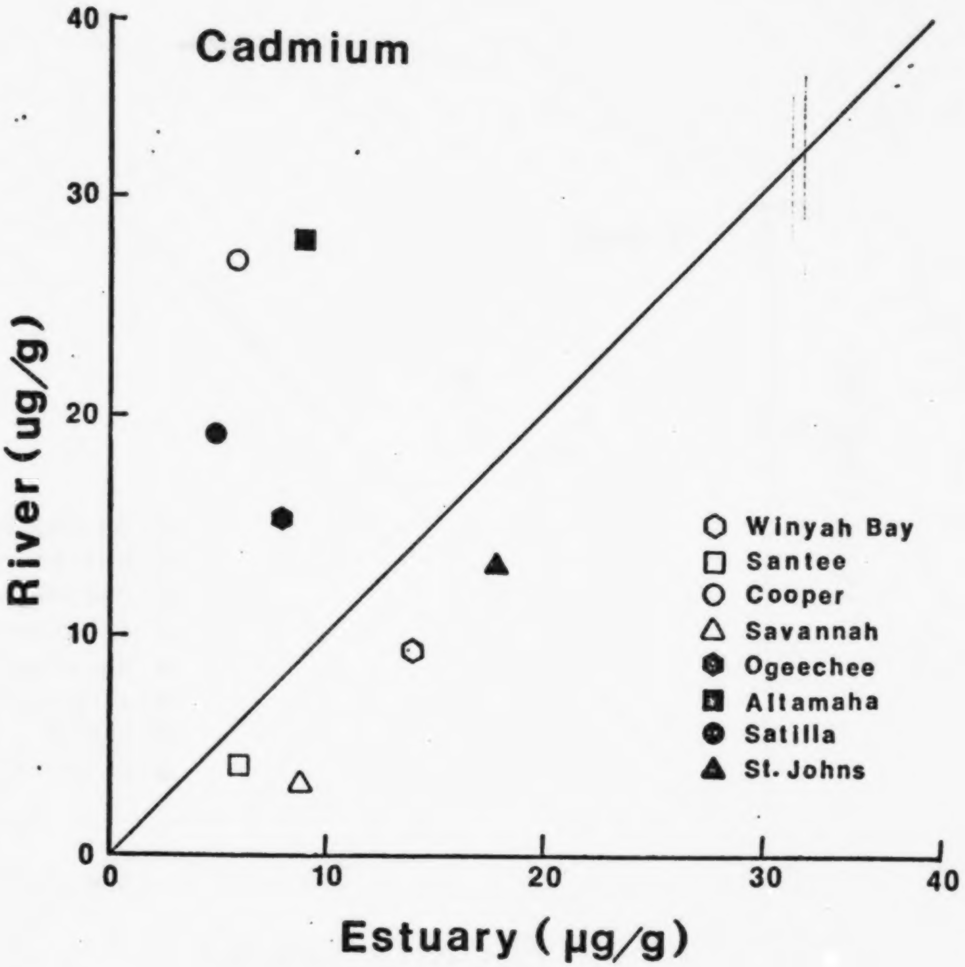

Figure 28. Cadmium in particulate matter of river versus that of estuarine water.

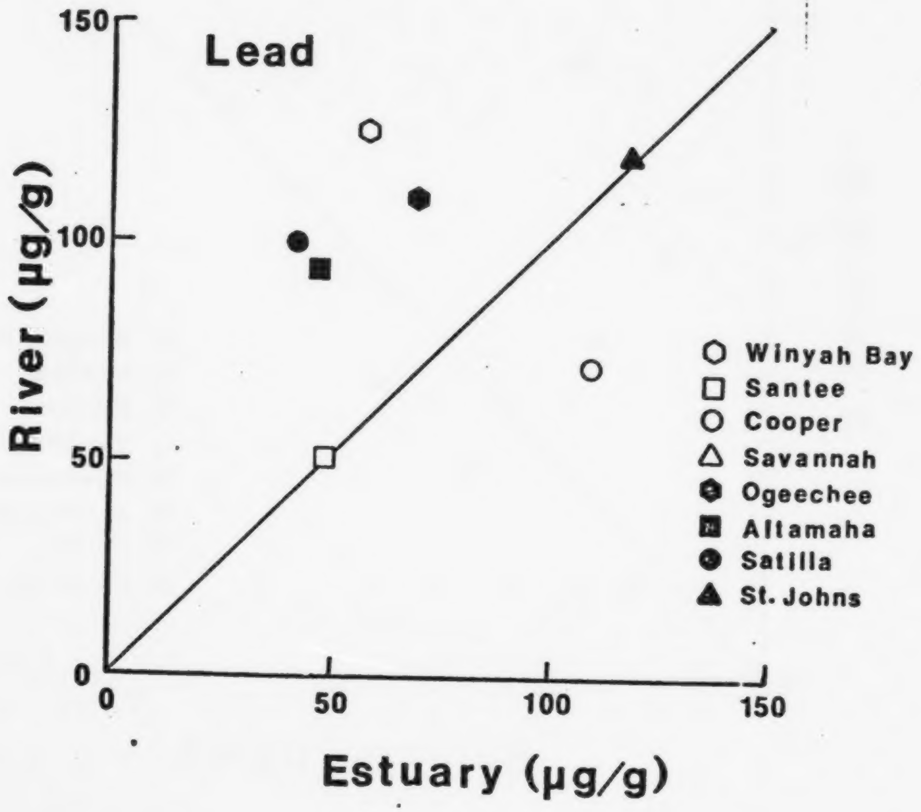

Figure 29. Lead in particulate matter of river versus that of estuarine water.

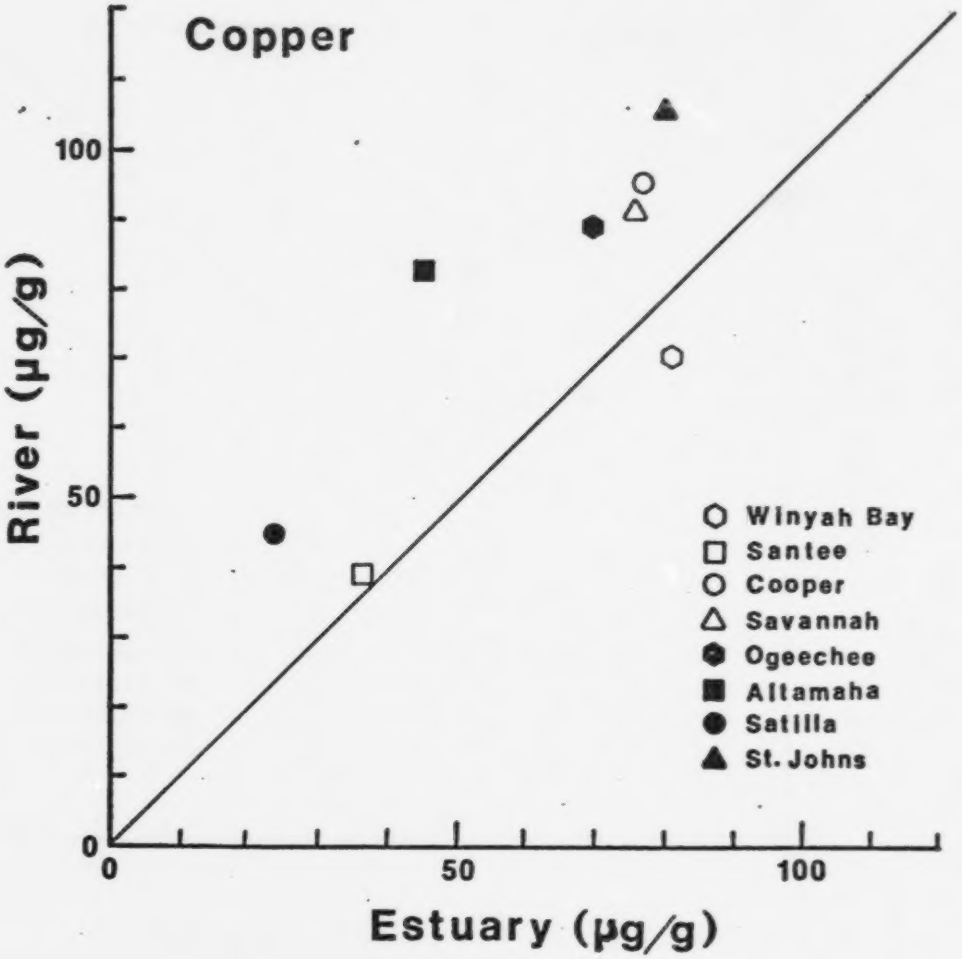

Figure 30. Copper in particulate matter of river versus that of estuarine water.

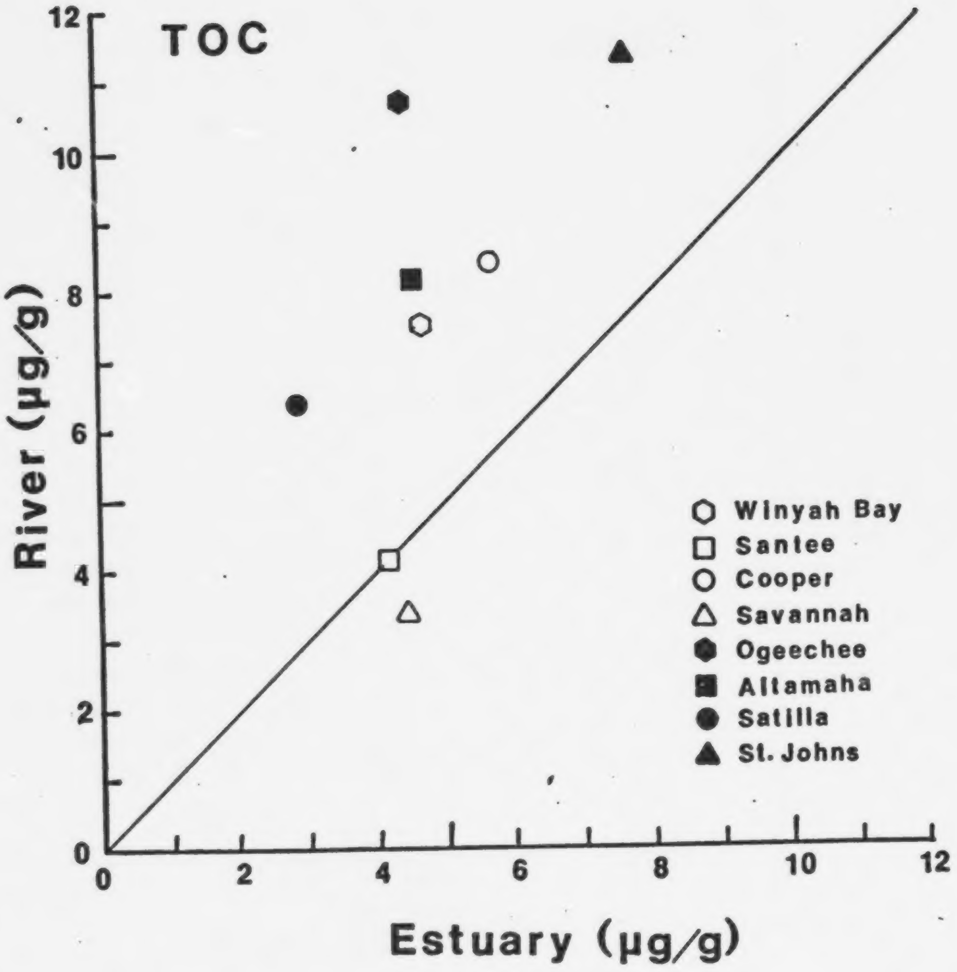

Figure 31. Total Organic Carbon in particulate matter of river versus that of estuarine water.

matter as shown in Figures 29 and 30. For example, Figure 32 and 33 show the relationship between copper and total organic carbon in particulate matter of freshwater and marine waters of the estuary respectively. Similar relationships can be seen in both figures, suggesting that copper is associated with the organic matter. This is probably true of lead as well. These data indicate that the decrease in copper and lead in suspended sediments of marine waters of the estuaries under study may be due to preferential flocculation and sedimentation of organic matter being transported into the estuaries at the fresh water-salt water interface.

4. Annual Discharge of Iron, Manganese, Copper, Mercury, Cadmium and Lead by Southeastern Rivers.

In order to determine the total flux of metals discharged by southeastern rivers into coastal waters, it is necessary to obtain seasonal data on the concentrations of the metals in these rivers. This data will also be important in determining the importance of the nearshore estuarine zone as a sink for these metals. One of the objectives in our study, therefore, has been to determine the concentrations of the metals in each of the rivers under study in relation to its discharge. Concentrations of the metals and discharge of the rivers at various times of the year can be integrated over the period of study providing annual discharge rates of each metal. As has been indicated earlier, however, data for a year period have not been obtained so the following discussion is based on data during May through December 1972 using average annual discharge rates of the given rivers over the past 20 years (Table 5). The rivers studied represent 96% of the total discharge along the southeastern Atlantic coastline between the North Carolina-South Carolina border and Cape Kennedy, Florida. This is a signi-

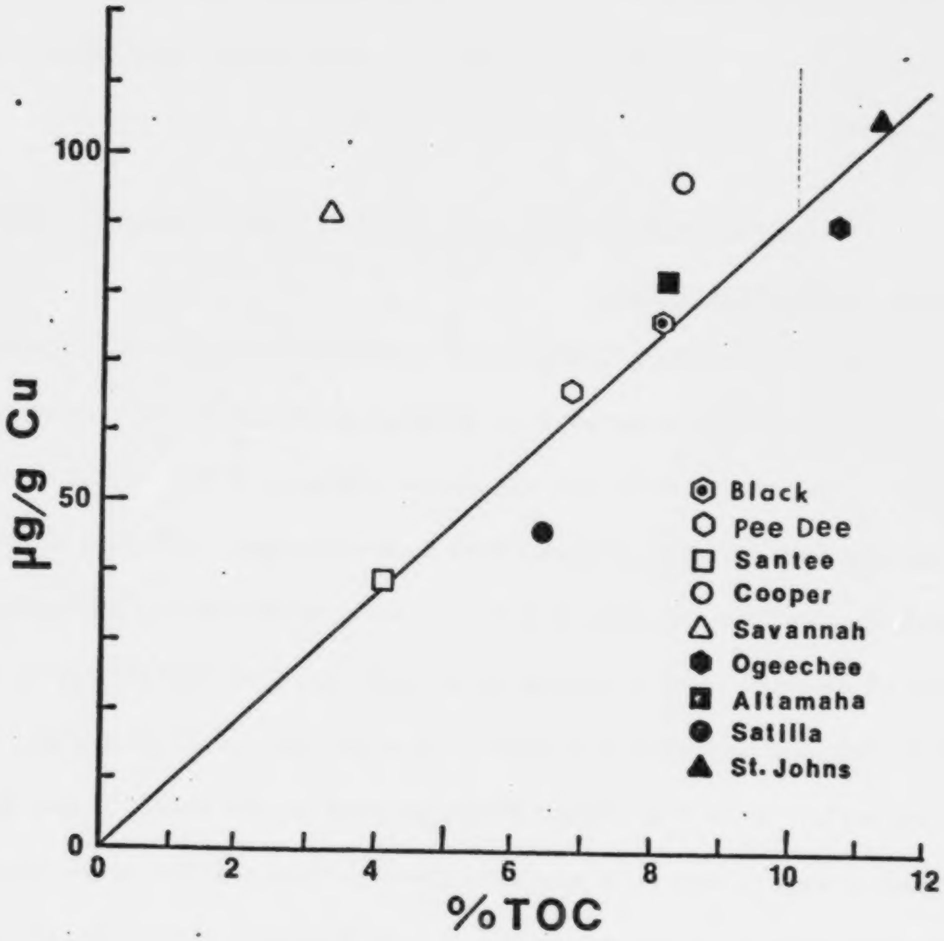

Figure 32. Copper versus TOC in southeastern river waters.

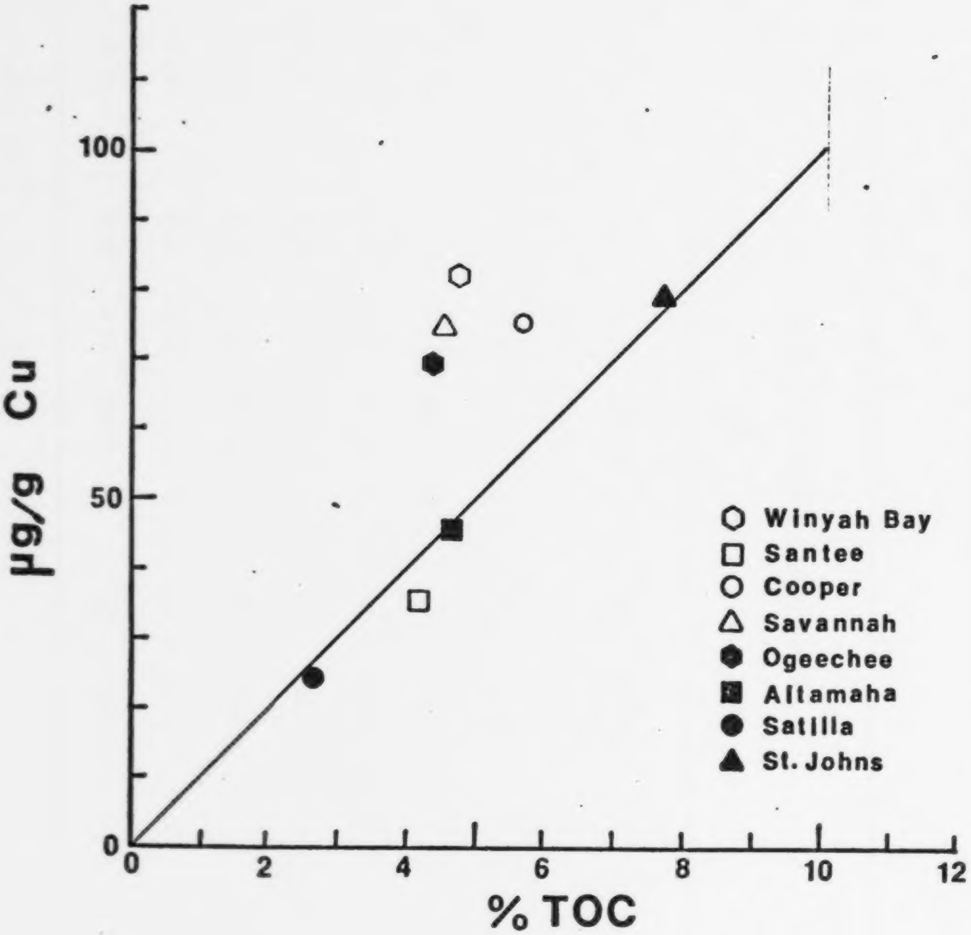

Figure 33. Copper versus TOC in southeastern estuarine waters.

TABLE 5

Metal Transport by Southeastern Rivers

River	Average Annual Discharge (10^{12}l)	Total Metal Concentration (μg/l)						Annual Metal Transport (10^6 kg)	Annual Metal Transport (10^3 kg)				
		Fe	Mn	Cu	Hg	Cd	Pb	Fe	Mn	Cu	Hg	Cd	Pb
Pee Dee	11.7	770	36	8	0.07	1.1	3.6	9.0	421	94	0.8	13	42
Black	0.8	980	42	10	0.10	1.6	3.5	0.8	34	8	0.1	1	3
Santee	1.9	4750	107	6	0.10	0.7	6.2	9.0	203	11	0.2	1	12
Cooper	12.7	220	11	5	0.09	1.2	2.0	2.8	140	63	1.1	15	25
Savannah	10.4	1750	65	7	0.12	0.6	4.4	18.2	680	73	1.2	6	45
Ogeechee	2.0	480	35	7	0.11	1.4	4.2	1.0	70	14	0.2	3	8
Altamaha	11.9	910	49	6	0.07	1.5	3.2	10.8	583	71	0.8	18	38
Satilla	2.0	1340	57	5	0.10	1.2	3.8	2.7	110	10	0.2	2	8
St. Johns	5.0	480	11	6	0.06	0.8	3.9	2.4	55	30	0.3	4	19
Total	58.4							56.7	2296	374	4.9	63	200

ficant part of the total discharge along the Atlantic coast from the United States. Using the annual runoff from the United States of 1485 x 10^{12} l/yr (Turekian, 1971) the total discharge of the rivers studied represents about 4% of the total.

As seen from Table 5 the discharge of the various metals is essentially proportional to the discharge of water since all rivers have similar total concentrations of the metals studied. Only iron shows significant variations in total concentrations between rivers. The similarity in concentrations of metals such as copper, mercury, cadmium and lead in the various rivers is due generally to the similarity in the composition of the drainage basins of the rivers studied. Variations in terrain and vegetation resulting in variations of organic matter probably account for the variation in iron. Table 6 indicates the percentage of the total metals carried by each river in particulate phases. Iron and manganese are carried predominantly in particulates phases. This has been shown to be true of major rivers of the world such as the Amazon and Yukon (Gibbs, 1973). The other metals however, appear to be transported primarily in soluble form. Gibbs, however, found that a very small percentage of the copper transported by the Amazon and Yukon Rivers was in dissolved phases. The differences between these rivers and the rivers of the southeastern United States may be due to the relative abundance of organic ligands available for complexation of metals such as copper, making them more soluble. The availability of organic ligands probably enhances the solubility of all of the metals studied in southeastern rivers.

5. Concentrations of Fe, Mg, Cu, Hg, Cd, Pb and Zn in Estuarine and Salt Marsh Sediments.

In addition to the studies designed to establish a data base for the concentrations of metals in the estuaries of the major rivers of the southeastern Atlantic coast,

TABLE 6

Per Cent Particulate of Total Metal Concentration in River Waters

River	Fe	Mn	Cu	Hg	Cd	Pb
	%					
Pee Dee	77	31	8	14	9	33
Black	79	40	9	20	6	40
Santee	98	94	50	50	43	64
Cooper	93	55	12	55	17	20
Savannah	94	72	37	17	17	39
Ogeechee	53	8	7	9	7	17
Altamaha	88	86	22	29	27	47
Satilla	67	11	16	10	25	47
St. Johns	89	64	20	17	13	33
Weighted Average	88	60	21	28	18	36

bottom and salt marsh sediments of the area were also collected in order to establish the distribution of metals in this compartment of the salt marsh-coastal littoral system. Cores were collected from salt marsh sediments throughout the study area at 25 locations (Figure 34). The salt marsh represents the dominant sink of metals in the estuarine system since it acts as a sediment trap and represents 75% of the total area of the estuarine environment. At each of 25 locations, cores were collected using a helicopter and brought back to the lab within a few hours and analyzed at 10 cm intervals for pH, Eh sulfide ion activity, percent moisture, total organic carbon, Fe, Mn, Cu, Hg, Cd, Pb and Zn. In the case of the metals, analyses were performed on both the total and the leachable fraction of the sediment (hydroxalminehydrochloride-acetic acid digestion, Chester and Hughs, 1967). In addition to the sediments, samples of Spartina alterniflora, the dominant primary producer in the study area, were collected at each of the sediment sampling core stations and also analyzed for the seven metals. This work is part of the NSF Study (IDOE GX-33615) which has overlapping interests. The results of these analyses for each core are given in Appendix I.

At the present time, the volume of these data has not allowed for complete evaluation. It is felt, however, that the types of information obtained will indicate any post depositional migration of the metals that may occur in the sediments. Data on clay mineralogy of the sediments has also been obtained to aid in the evaluation of metal distribution in the marsh sediment. These are given in Appendix 2.

A summary of the metal concentrations in marsh sediments is given in Table 7 which lists the average concentration of the metal throughout the length of each core. As can be seen from these results, the metal composition of the sediments from location to location is quite similar. The relationship between cores is reflected

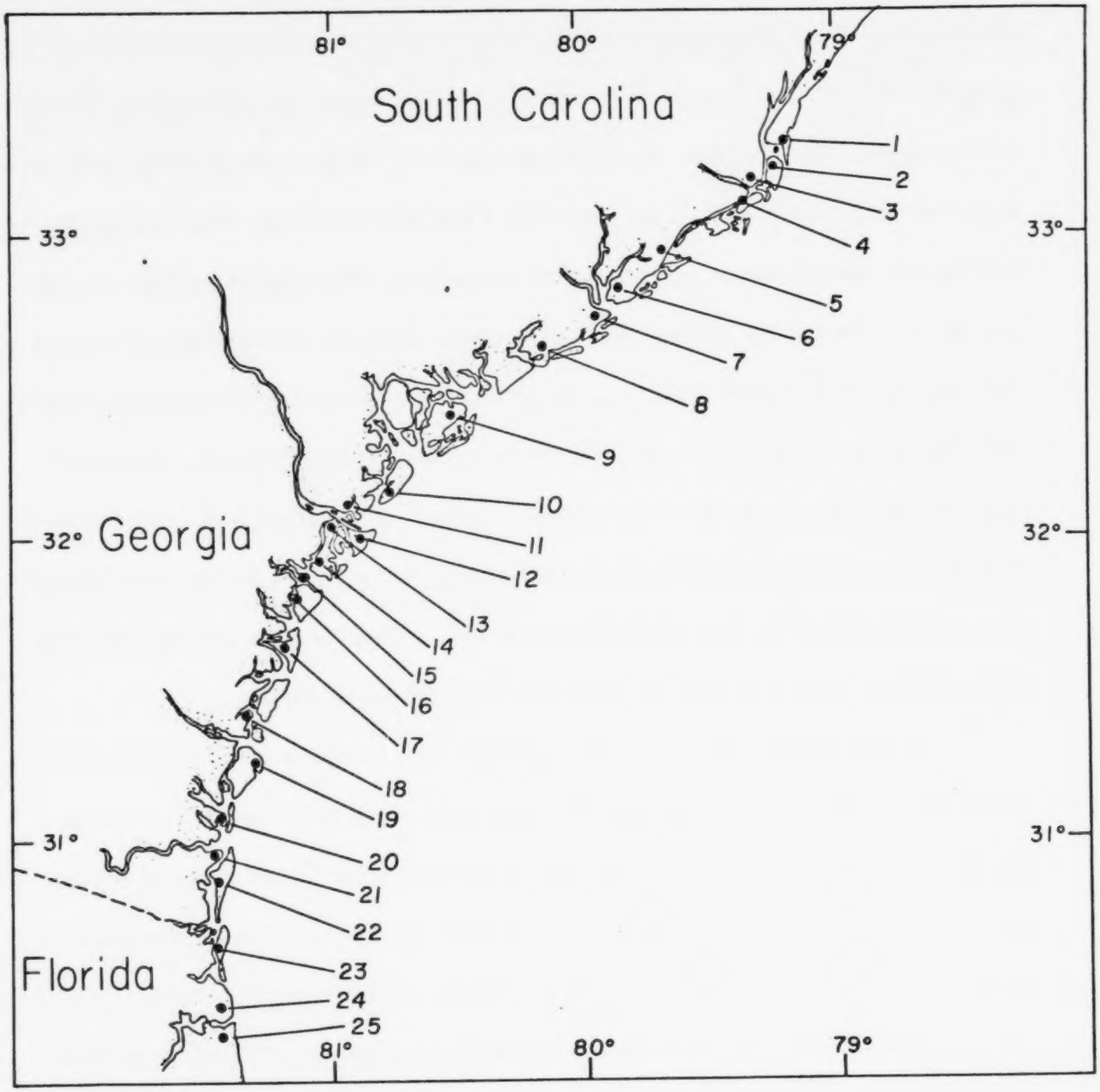
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Figure 34. Location of Marsh Sediment Coring Stations.

TABLE 7

Average Metal Concentrations in Marsh Cores
(Dry Weight Basis)

Station	%	ppm				
Number	Fe	Mn	Cu	Hg	Cd	Pb
1	3.9	103	30	0.12	3.4	25
2		250	16	0.09	5.0	26
3	3.9	166	26	0.16	2.9	20
4	5.0	142	25	0.05	3.3	20
5		209	24	0.08	4.4	27
6		158	10	0.01	1.0	16
7	1.2	139	4	0.04	0.4	9
8	1.8	114	4	0.02	0.8	9
9	4.1	309	16	0.04	2.1	13
10	1.9	174	3	0.04	0.1	4
11	2.4	151	8	0.06	0.5	8
12	4.8	260	12	0.09	0.6	16
13	4.6	353	20	0.16	0.8	21
14	3.4	319	10	0.10	0.4	20
15	4.0	173	10	0.11	0.8	19
16	2.9	366	8	0.02	0.8	15
17	2.7	262	6	0.05	0.2	20
18	3.2	273	12	0.16	0.8	24
19	1.1	175	4	0.03	1.6	11
20	3.7	168	8	0.06	0.8	15
21	3.1	244	8	0.07	1.2	12
22	4.7	132	7	0.06	0.8	13
23	2.9	128	10	0.08	0.7	20
24	0.9	205	5	0.05	0.8	15
25	1.5	74	2	0.05	0.4	9
Mean	3.1	202	11	0.07	1.4	17

in the variation of mercury with total organic carbon shown in Figure 35. The line drawn in this figure is a linear regression curve of the data. Even though a significant linear correlation is observed, the data does not necessarily suggest a linear relationship between mercury and TOC, but probably indicates that the maximum level of mercury is probably controlled by the total organic carbon in the sediment. The high concentrations of mercury in the salt marsh vegetation (which probably makes up a large fraction of the organic carbon in the marsh sediments) probably represents the source of a large portion of the mercury in salt marsh sediments. Other investigators (Anderson, 1967; Kennedy, et al., 1971) have also found a correlation between mercury and total organic carbon.

Generally, metals in samples taken from bottom sediments of the major river estuaries occur in concentrations similar to those of marsh sediments. For example, sediment samples taken from several stations in the Cooper River, adjacent to Charleston, South Carolina (Figure 36), contain concentrations of metals (Table 8) similar to those of the salt marsh sediments. Even though these sediments receive the effluents from industries as well as the city of Charleston, the concentrations of the metals are not much higher than those in unpolluted areas. However, it is interesting to notice that the concentrations of cadmium, copper and lead in most of the samples from Charleston Harbor are higher than the average of the salt marsh sediments, while many have higher mercury concentrations than the marsh sediments.

From the above data, it is clear that the sediments of the coastal area of the southeastern United States are relatively uniform in metal concentrations. If the rate of accumulation of the sediments is known, the rate of loss of these metals in the sediment sink can be determined. Under our NSF research grant we have deter-

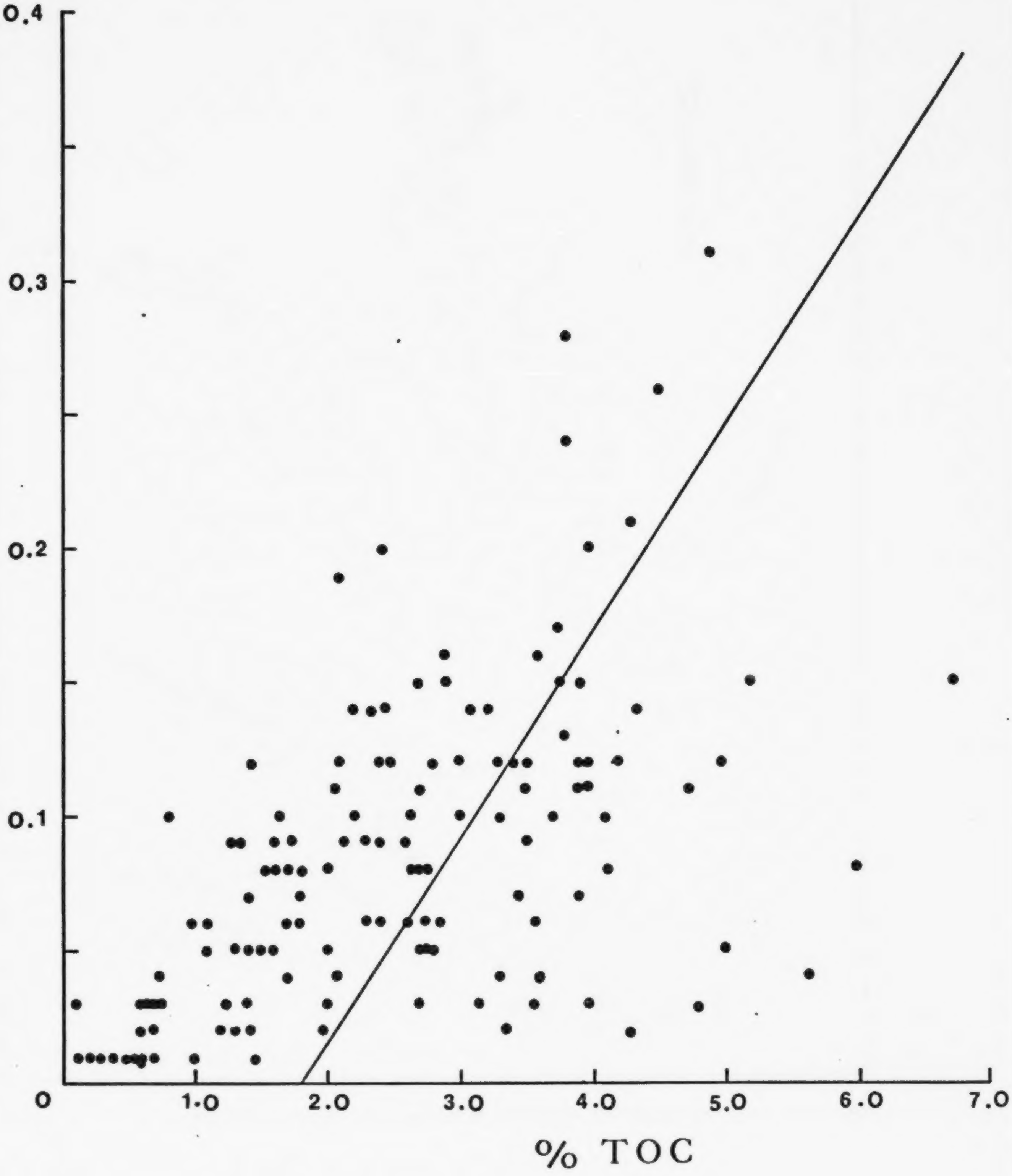
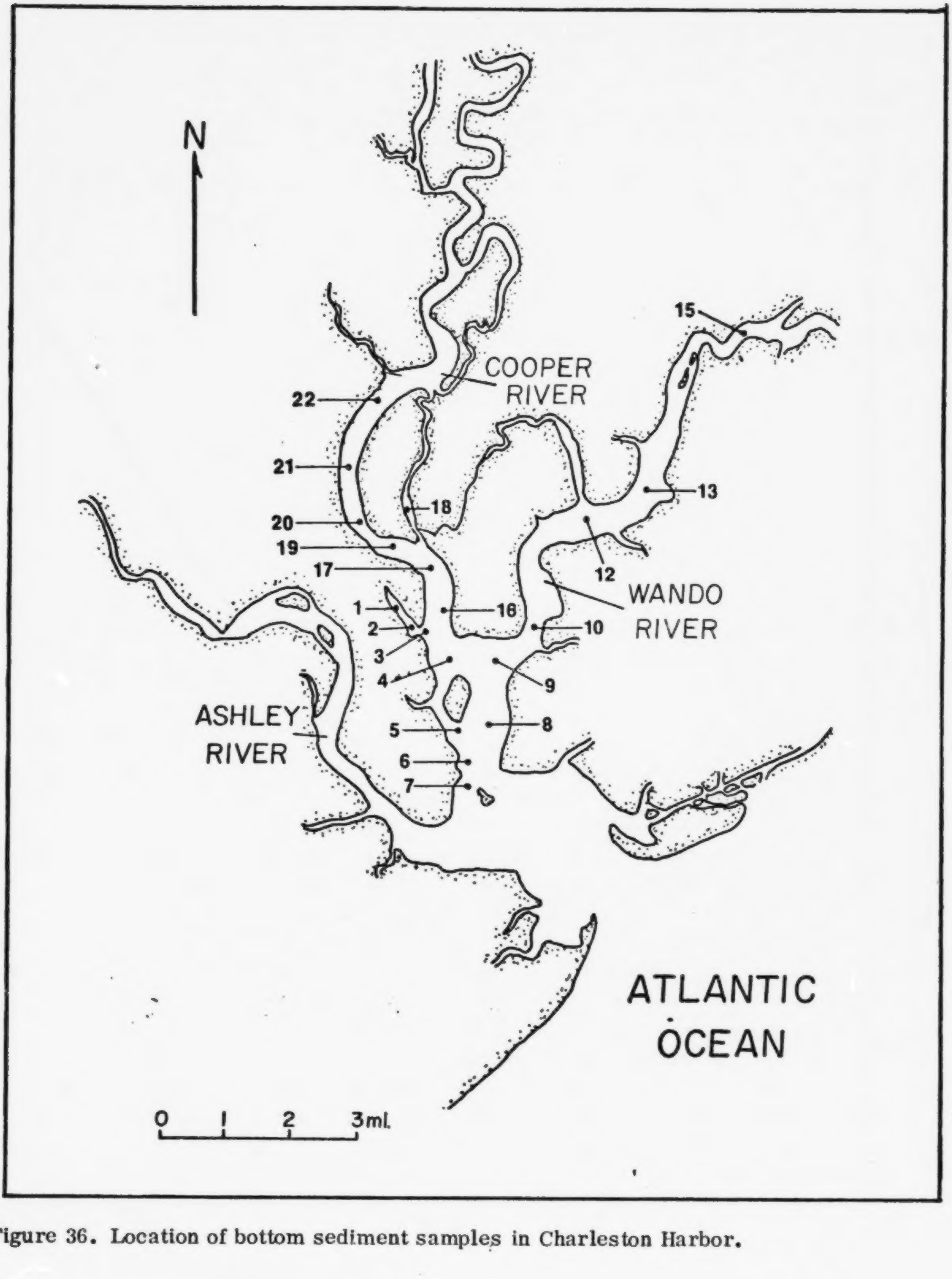


Figure 35. Mercury versus total organic carbon for salt marsh sediments.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WANDO RIVER
ASHLEY RIVER
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Figure 36. Location of bottom sediment samples in Charleston Harbor.

TABLE 8
Metal Concentrations in Charleston Harbor Sediment Samples:

Sample	%		ug/g (dry wt.)										
	Fe		Mn		Hg	Cd		Cu		Pb		Zn	
	Total	Leach	Total	Leach	Total	Total	Leach	Total	Leach	Total	Leach	Total	Leach
1		0.70	210	210	0.24	9.5	0.8	38	3.6	33	30	120	100
2		0.09	620	56	0.12	2.8	<0.1	28	3.8	73	5.0	120	40
3	5.8	0.64		860	0.14	6.8	1.0	29	7.2	34	30	90	68
4	8.2	0.28	240	120	0.04	1.2	1.0	16	1.8	21	9.5	39	12
5	6.2	0.53	420	420	0.13	9.1	<0.1	25	3.4	29	24	83	48
6	7.8	0.51	610	520	0.15	2.7	0.7	24	13	23	22	80	51
7		0.47	640	170	0.21	1.2	0.7	23	4.9	34	21	84	60
8		0.09	180	79	0.03	0.7	0.2	7.7	5.9	11	4.9	29	79
9		0.10	200	72	0.03	1.3	<0.1	4.7	4.0	8.3	6.0	32	22
10		0.20	320	79	0.05	1.3	<0.1	12	1.2	15	8.3	75	36
12		0.38	230	210	0.03	3.0	0.6	8.7	1.2	9.4	9.0	26	40
13		0.06	190	20	0.01	<0.1	<0.1	3.2	2.8	3.6	3.0	10	10
15	1.4	0.06	250	130	0.01	<0.1	0.1	2.9	2.9	6.6	5.9	10	10
16		0.90	83		0.01	5.1	1.6	28	9.0	26	25	47	47
17	3.5	0.40		140	0.09	1.1	0.6	19	3.9	16	10	49	49
18	6.2	0.50	360	310	0.20	3.5	1.0	36	3.8	20	20	110	58
19		0.09	220	54	0.03	0.5	<0.1	16	5.8	15	7.3	49	33
20	8.3	0.46	63		0.08	0.3	0.3	18	2.2	29	18	81	46
21		0.50		280	0.27		1.0		53		260		600
22		0.13		110	0.05	4.0	0.6	25	1.2	30	11	79	34

mined the C^{14} ages at various levels within two cores from the area. The results of these analyses are shown in Table 9 and displayed graphically in Figure 37. The rates of accumulation vary at different levels in the sediment but remain close to 1mm/yr. In fact, the average sedimentation rate for both cores is 0.7 mm/yr which is close to the 1 mm/yr average rate of accumulation for coastal marsh sediments calculated by Rusnak (1967) based on eustatic changes in sea level. Using this rate and the average concentrations of metals in salt marsh sediments (which should represent the general concentration of sediments in the salt marsh-coastal littoral environment) the rate of loss per unit area of each metal can be calculated. These rates are given in Table 10. As will be seen below, these rates of loss of metals will be important in determining the flux of the metals through the estuarine system.

B. Hydrographic Studies

Data has been accumulated on the hydrography of the Winyah Bay area during four cruises aboard the R/V Golden Isles (operated under a NSF Ship Grant). These cruises were made September 4th through the 8th, November 14th through the 19th, December 11th through the 16th, and March 21st through the 20th. One additional cruise is planned for May 14th through the 19th. This is the initial hydrographic study designed to provide information on coastal transport of metals subsequent to entry into the estuaries of the major southeastern rivers. The general area of this study in relation to the total study area is shown in Figure 38.

During the September and March cruises stations external to the estuary were occupied (Figure 39). Current velocity and directions were recorded at five minute and twenty minute intervals for at least a tidal cycle at each station. Temperature and

TABLE 9

Carbon 14 Ages of Marsh Sediments

Depth cm	Age (years before present)	
	Core # 17	Core # 22
0	335 ± 70	0
35	470 ± 90	210 ± 60
70	1050 ± 125	980 ± 90

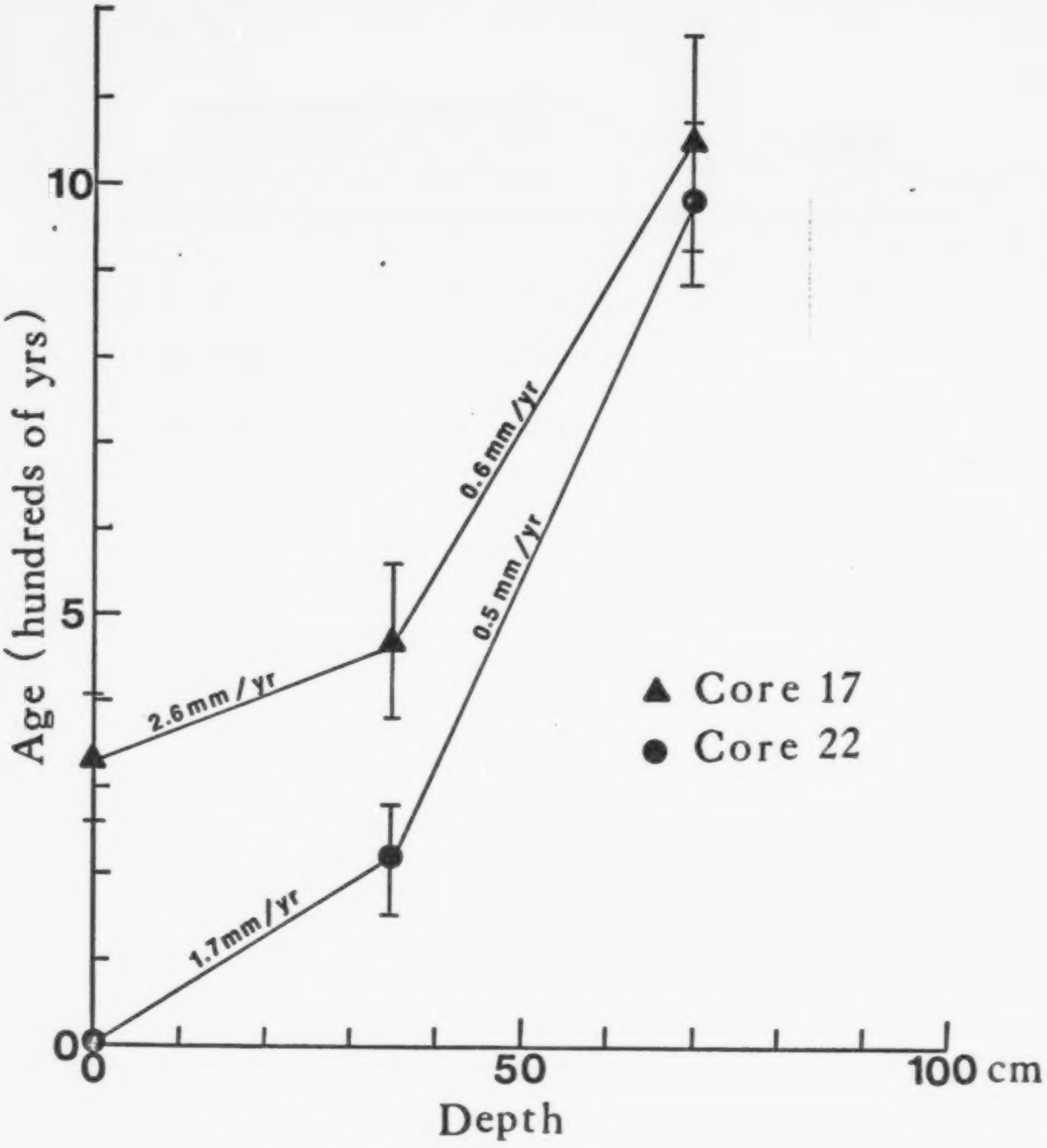


Figure 37. C^{14} age versus depth in two salt marsh sediment cores.

TABLE 10

Accumulation Rate of Metals in Salt Marsh Sediments

Metal	Accumulation Rate	
Fe	31	$g/m^2 . yr$
Mn	202	$mg/m^2 . yr$
Cu	11	"
Hg	0.07	"
Cd	1.4	"
Pb	17	"

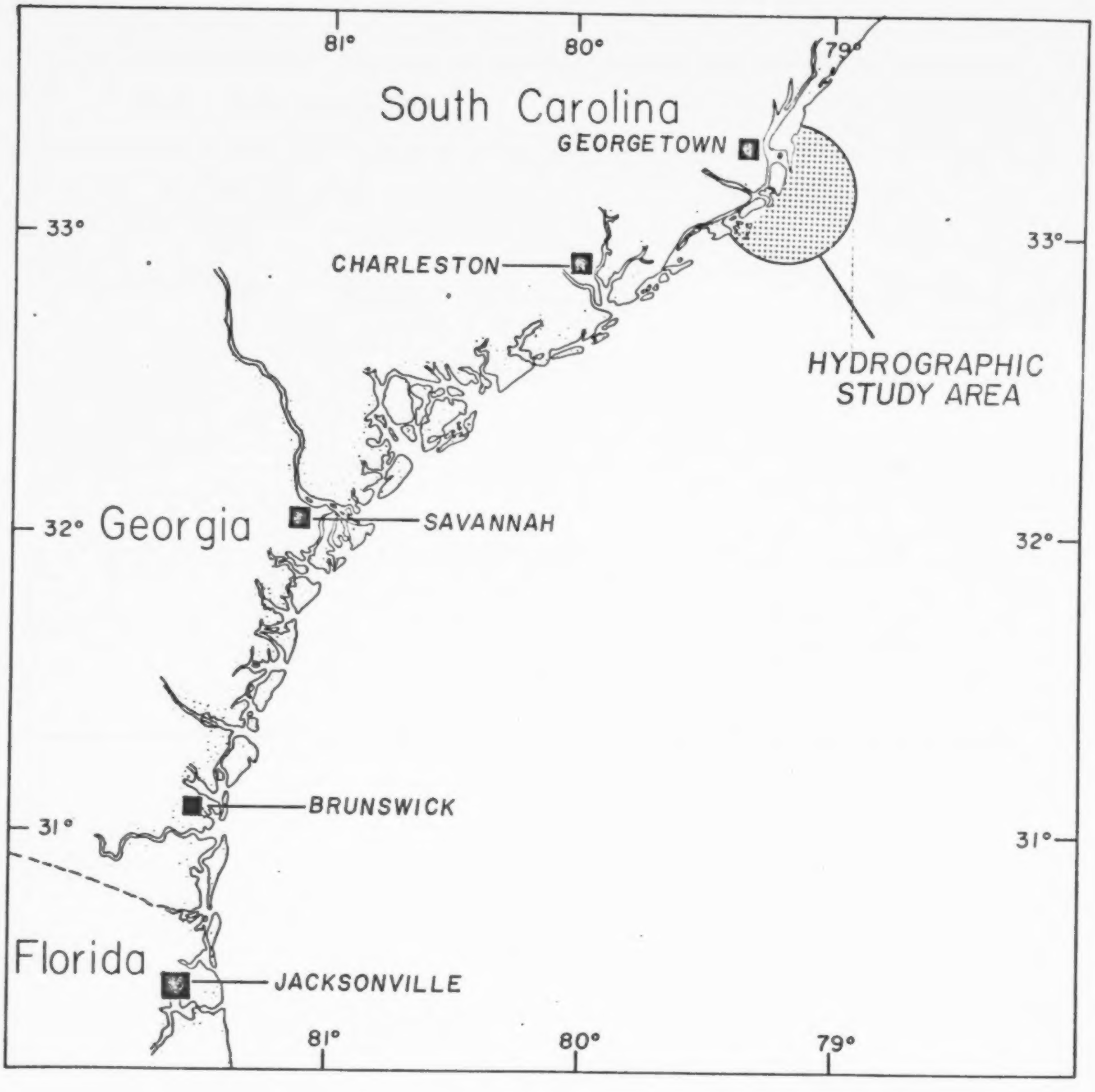

81°
80°
79°
South Carolina
GEORGETOWN
33°
CHARLESTON
33°
HYDROGRAPHIC STUDY AREA
32°
Georgia
SAVANNAH
32°
BRUNSWICK
31°
31°
Florida
JACKSONVILLE
81°
80°
79°

Figure 38. Location of Hydrographic Study Area.

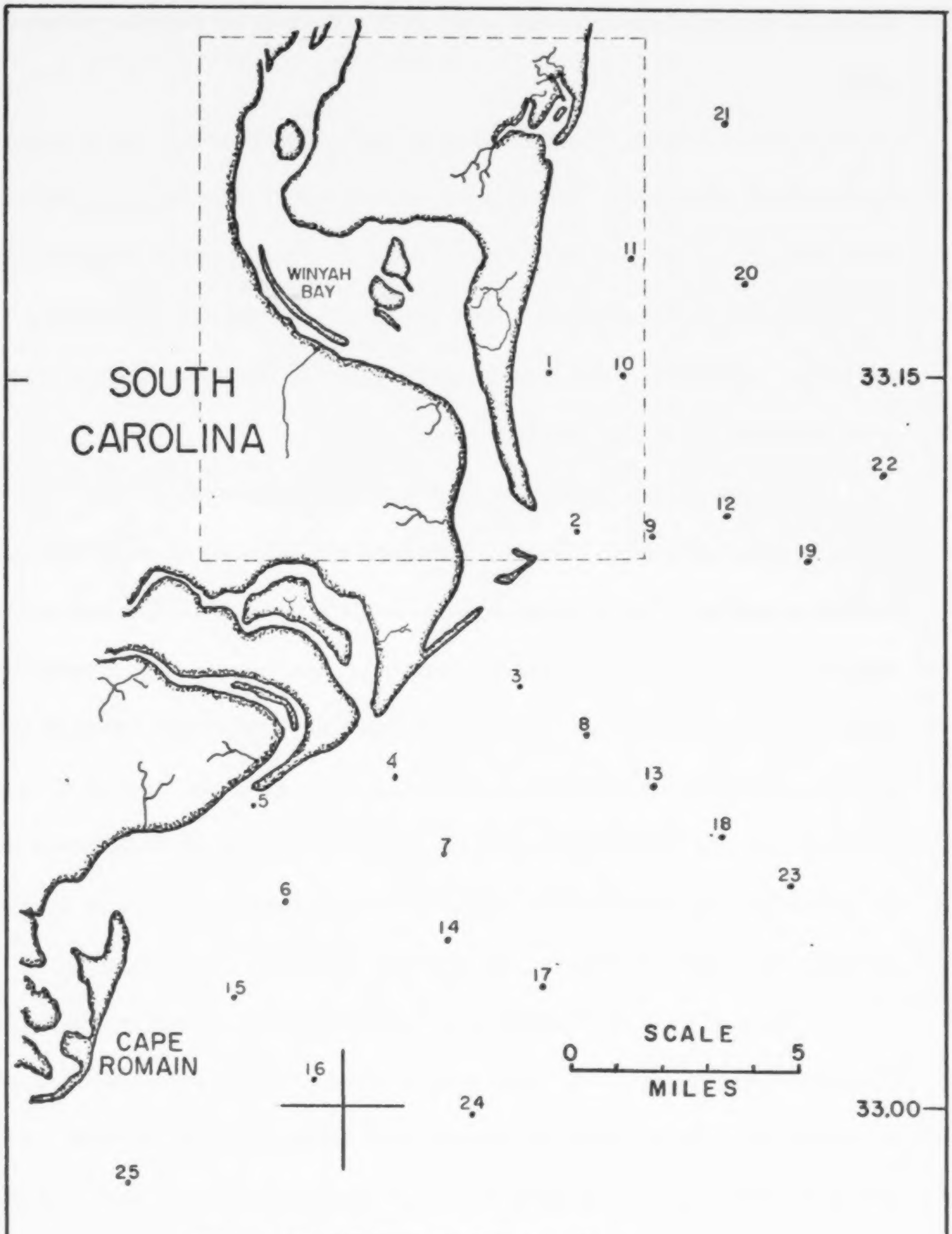

WINYAH BAY
SOUTH CAROLINA
CAPE ROMAIN
33.15
33.00
79.15
SCALE
0
5
MILES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Figure 39. Offshore Station Locations.

salinity of surface and bottom waters was also taken at these stations in an effort to determine degree of stratification in the shelf waters at the time the measurements were made.

The November, December and the bulk of March cruises were confined to the estuary itself (Figure 40). Temperature and salinity at three foot intervals of depth were taken at several stations within the estuary. Four complete cross-sections of the estuary were compiled during the March cruise and a fifth was made during the November cruise. Current measurements were made every five minutes for at least a tidal cycle at points marked by dots in Figure 40.

Current meter measurements were made with General Oceanics model 2010 recording current meters. The meters consist of a buoyant poly-vinyl chloride cylinder with two stabilizer fins attached to the exterior (Figure 41). Contained within the cylinder there is a super-8 cartridge camera, a light source, a directional inclinometer and a watch. The camera is oriented such that it will take a picture of the inclinometer and the watch thus recording the time direction and amount of inclination of the meter. The inclination is directly related to the velocity of the water flowing by the meter. The system can be set so that it will record a reading at intervals of 10 seconds, one minute, 5 minutes, 15 minutes, 30 minutes, or 60 minutes.

The meters were attached to wire cables by a snap hook restrained between two cable clamps (Figure 42). This system of mounting is quite simple and easy to work with and it allows sufficient freedom of movement for good results. The lower end of the mounting cable is attached to a one hundred pound concrete or lead anchor with a swivel and shackle to allow the cable to twist without kinking. The upper end of the cable is secured to a fluorescent orange marker bouy (2' diameter) by means of

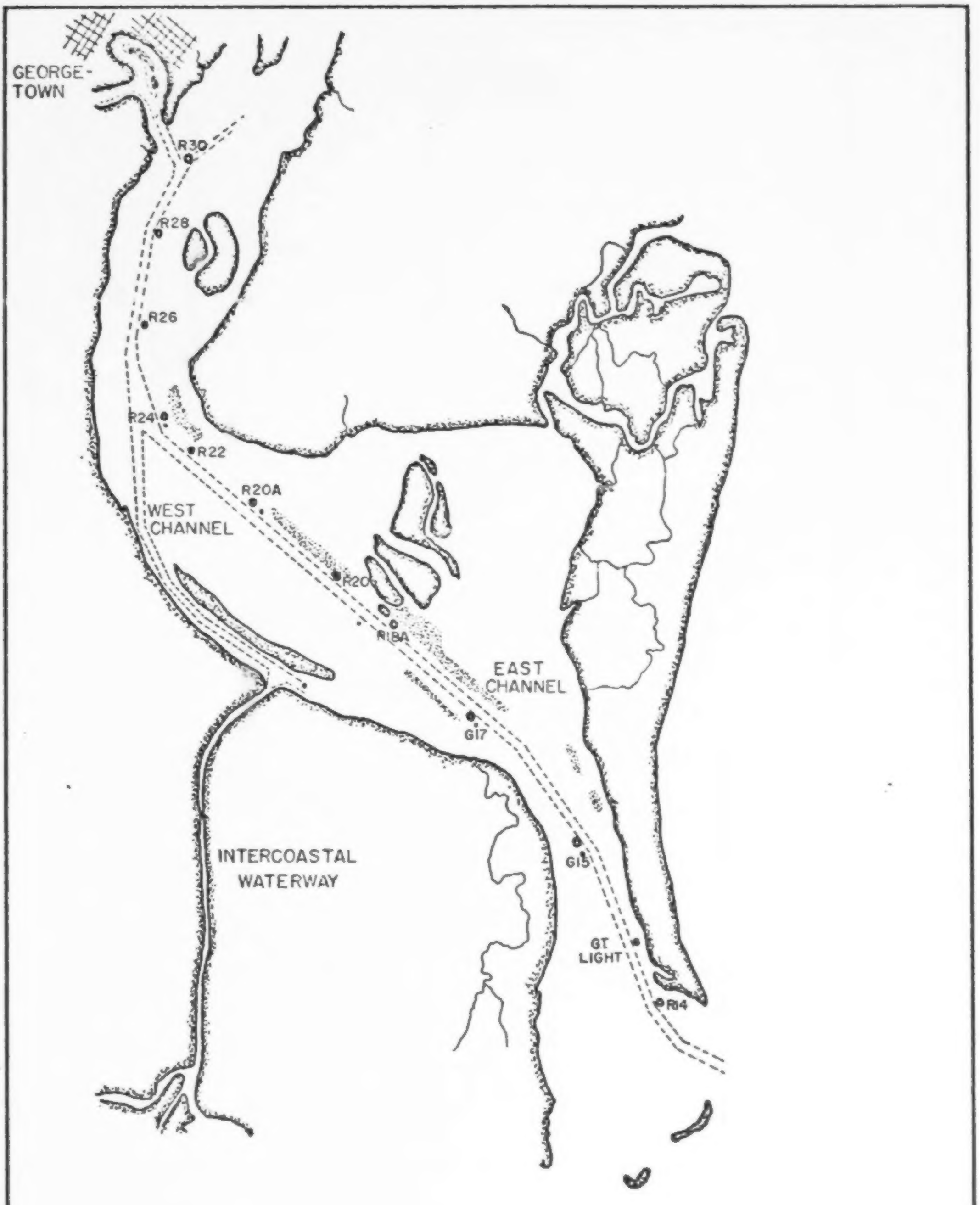
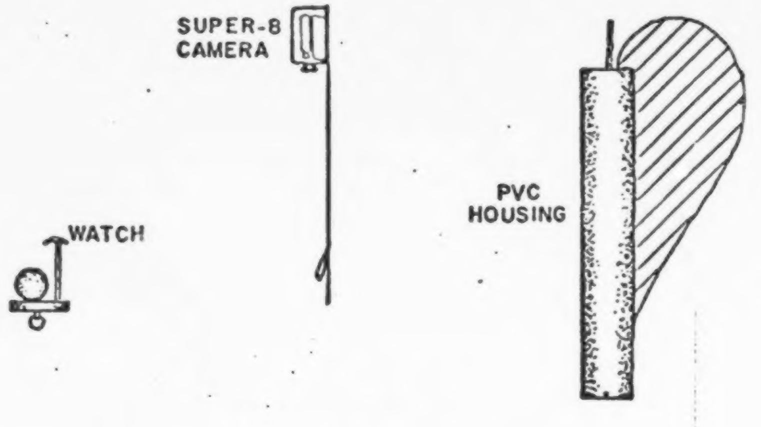

GEORGE-
TOWN
R30
R28
R26
R24
R22
R20A
WEST
CHANNEL
R20
R18A
EAST
CHANNEL
G17
G15
INTERCOASTAL
WATERWAY
GT
LIGHT
R14

Figure 40. Station locations in Winyah Bay. (Circles indicate where temperature and salinity measurements were made.


SUPER-8
CAMERA
WATCH
PVC
HOUSING

DISASSEMBLED

ASSEMBLED

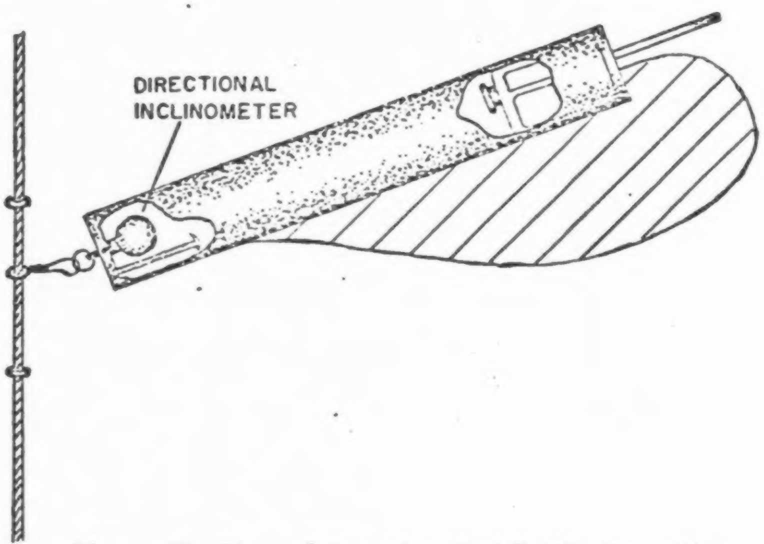

DIRECTIONAL
INCLINOMETER

Figure 41. General Oceanics Model 2010 Recording Current Meter.

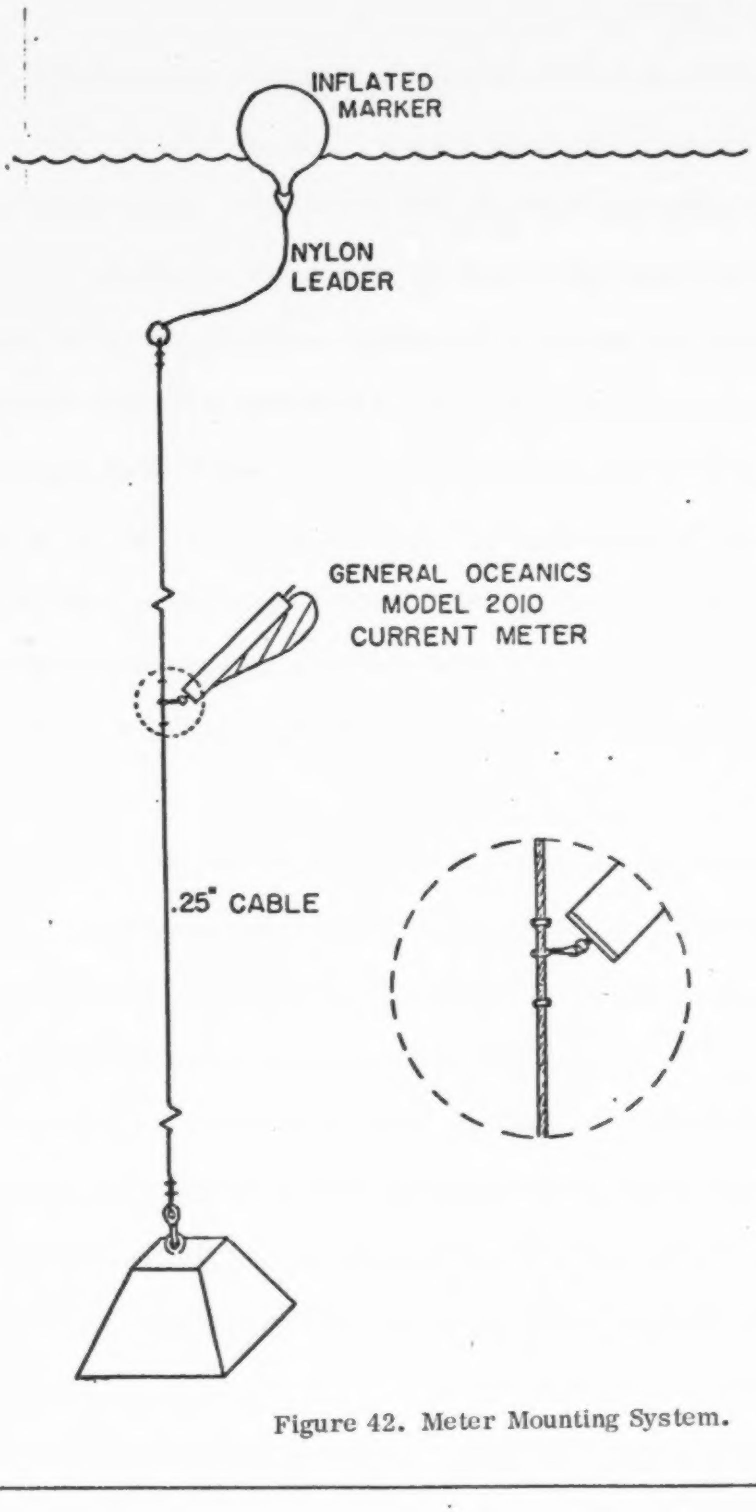

INFLATED MARKER
NYLON LEADER
GENERAL OCEANICS MODEL 2010 CURRENT METER
.25" CABLE

Figure 42. Meter Mounting System.

a half inch nylon leader.

Salinities are measured with a Beckman salinometer temperature probe. This instrument is adequate for measuring changes in salinity of greater than one part per thousand which is sufficient for the purposes of this study. Wind velocity and direction are measured using a hand held anemometer and the ships compass.

All current data external to the estuary in presently being vectorally averaged for each hour the meters were in the water. The current data within the estuary was separated into flood and ebb components and the velocities for each component were averaged over their duration. The result is an average flood velocity, an average ebb velocity, and a duration for each of these phases. The difference between the average velocity times the duration for each phase yields the dominant current direction.

Volume runoff data was acquired through the U.S.G.S. Water Resources Division.

Thus far data resulting from the first, second and third cruises have been transferred from the film recordings and reduced. Data recorded during the fourth cruise have been completely transferred but not reduced. The data external to the estuary indicate that the waters in this area respond primarily to dominant wind conditions and secondarily to tidal influences. There is evidence for a minor disruption of otherwise continuous water motion occurring, at least occassionally, following high tide on the shelf. Preliminary evidence suggests that this phenomena may result from a dynamic barrier produced by the interaction between shelf water circulation and the movement of waters in the nearby estuary.

The data taken within the estuary suggest that the estuary fits best into the "partially mixed" category but complications resulting from configuration of the estuary and fluctuations in volume runoff can complicate this rather simplified classification. At times of average to high runoff the water near the mouth of the estuary can be partially stratified. The waters in the western channel also may have a tendency to become somewhat stratified as preliminary evidence suggests that a disproportionately large fraction of the incoming fresh water flows through this channel as opposed to the larger eastern channel. These conclusions are all tenative and may or may not prove valid upon inspection of additional data presently being obtained.

IV. LABORATORY STUDIES

Laboratory studies have been initiated on three aspects of geochemical interactions which affect the transport and fate of metals at the river-salt water boundary. Specifically these studies have been designed to, 1) investigate the characteristics of the dissolved organic matter of the rivers, 2) elucidate the flocculation process at this boundary and investigate the nature of floccules and, 3) to quantify the stability constants of metal-organic acid complexes. All of these studies are in their initial phases, requiring information from the field studies to put their results into the proper frame of reference. Nonetheless, progress has occurred in these and this is described in the following sections.

A. Characterization of Dissolved Organic Matter.

Chemical characterization of dissolved organic matter in river waters has been pursued with the objective to determine its "environmental activity". By "environmental activity" we understand the ability of the naturally occurring, water soluble, stable organic matter to interest with inorganic dissolved species, such as by adsorption, "salt" formation and chelation, and to donate hydrogen ions in the process, thus determining the chemistry of natural aqueous systems. These interactions will be of importance especially in rivers with a high organic-inorganic matter ratio, a condition found in many of the streams discharging along the southeastern Atlantic coast.

Important parameters that give a measure of "environmental activity" as defined above, are the oxygen-containing functional groups, specifically in this case carboxyl (-COOH) and phenolic hydroxyl (-OH). The sum of these two groups are determined by measuring total exchangeably hydrogen (total acidity). Carboxyl content is determined by an independent method, and the concentration of phenolic hydroxyls is then expressed as the difference of total acidity and carboxyl content.

We have chosen to work with water samples that have a high initial concentration of the organic matter (see Table 11). It was nevertheless necessary to concentrate several hundred liters of water by vacuum evaporation and freeze-drying to obtain a sufficient amount of material.

The organic matter under investigation represents a complex polydispersed system. In order to obtain more homogeneous fractions for the chemical characterization, the raw material extracted from the river water is first purified by ion-exchange desalting. The purified (desalted) organic matter is then fractionated by gel permeation chromatography (GPC). Since our investigations showed interesting adsorption between the organic matter and the Sephadex gels, we decided to consider only those GPC-fractions as homogeneous which have the least chance of interaction with the gel. These are the "excluded" fractions (Figure 45). The "retarded" fractions were rechromatographed on Sephadex gels with lower molecular weight fractionation ranges (in the order G-50> G-25> G-15> G-10), and only the "excluded" fractions were used for further analysis. An exception is the "retarded" fractions from the lowest

TABLE 11

Dissolved Organic Data

Sample	Wt (g)	% of Total	% of Fraction After Desaltation
RS-19	4.934g/120L		
G-50 Excluded	0.1062	19.5%	
G-25 Excluded	0.0772	14.1%	
G-15 Excluded	0.0741	13.6%	
G-15 Retarded A	0.1004	18.4%	
G-15 Retarded B	0.1521	27.9%	
G-15 Retarded C	0.0358	6.6%	
	.5458	100.1%	
RS-36A Raw	31.2g/240L		
RS-36A (Desalted)	19.2379g	$\frac{19.2379}{29.226} = 65.8\%$	$\frac{.2387}{.2494} = 95.7\%$
G-50 Excluded	.2387	4.6%	$\frac{2.8021}{3.2524} = 86.2\%$
G-25 Excluded	2.8021	54.1%	$\frac{.3472}{.9896} = 35.1\%$
G-15 Excluded	.3472	6.7%	
G-10 Excluded	.7723	14.9%	$\frac{.7723}{1.0063} = 76.7\%$
G-10 Retarded	1.0175	19.7%	
	5.1778	100.0% $\frac{5.1778}{6.2900} = 82.3\%$	$\frac{1.0175}{1.4255} = 70.2\%$
G-50 Excluded'	.2494	3.6%	
G-25 Excluded'	3.2524	47.0%	
G-15 Excluded'	.9896	14.3%	
G-10 Excluded'	1.0063	14.5%	
G-10 Retarded'	1.4255	20.6%	
	6.9232 (difference = 0.5%)	100.0%	
RS-36B Raw	37.45g/24OL (156 ppm)		

' Not desalted based on weight of G-50 Excluded + G-50 Retarded = .2494 + 6.6387 = 6.8881 molecular weight range of Sephadex G-10. Figure 43 shows detailed gel permeation chromatograms. The "excluded" fractions are the peaks with the lowest elution volume and the smallest K_d values. Table 11 summarized the results of the fractionation in terms of weight percentages of the individual GPC fractions as well as losses occurred during the individual desalting steps. Table 12 shows the results of oxygen containing functional group analyses, expressed in milliequivalents per gram. Results for the GPC-fractions of RS-36 have not yet been obtained. The concentrations of oxygen containing functional groups clearly characterize the dissolved river water organic matter as humic substances. A comparison especially with soil fulvic acids reveals a striking resemblance of river water organic matter with these intensively studied soil humic fractions. Infrared spectroscopy of dissolved river water organic matter substantiates the chemical data (Figure 44), especially absorption in the following regions: The broad intense band centered around 3400 cm^{-1} corresponds to the stretching frequencies of hydrogen bonded O-H, the strong absorption band at 1720 cm^{-1} is due largely to C=O stretching in carboxyl groups. Comparison with infrared spectra of soil fulvic acids shows a strong resemblance in spectral type.

The results of the elemental analysis (C, H, N, O) are tabulated in Table 13. The ash content is mainly due to the presence of silica, iron oxides and alumina. The fact that even after desalting a certain percentage of ash remains in the sample is probably due to strong complexing of Fe and Al, both of which are only partially removed in the desalting step. The elemental composition of dissolved river water organic matter reveals another striking resemblance with soil fulvic acids. The correlation between oxygen content and concentration of oxygen containing functional groups is obvious: in general, lower molecular weight fractions show higher total acidities and

TABLE 12

Elemental Analyses of D. O. M.

Sample[1]	C	H	N	O[2]	ASH
RS-19					
Desalted[3]	49.37	4.00	1.14	45.49	15.60
G-50 Excluded	52.17	4.07	1.20	42.55	3.58
G-25 Excluded	50.74	3.44	0.92	44.87	2.08
G-15 Excluded	50.38	3.57	0.91	45.19	2.39
G-15 Retarded A	39.95	4.04	0.78	55.26	1.15
G-15 Retarded B	43.06	3.94	1.04	51.96	1.89
G-15 Retarded C	53.79	4.44	1.17	40.60	4.57
RS-36A[3]					
Raw	49.35	3.69	0.82	46.15	7.65
Desalted	52.07	3.58	0.77	43.54	2.30
G-50 Excluded					
G-25 Excluded					
G-15 Excluded					
G-10 Excluded					
G-10 Retarded					
RS-36B[3]					
Raw	48.17	3.85	1.08	46.85	15.56

---

[1] Percent of C, H, N, and O expressed on an ash free basis

[2] Percent O calculated by difference

[3] Data represents average of duplicate analyses

TABLE 13

Oxygen Containing Functional Group Analyses (MEQ/GRAM)[1]

	Total Acidity	Carboxyl Groups	Phenolic OH[2]
RS-19 PARENT	10.97	8.31	2.66
G-50 Excluded	8.90	4.47	4.43
G-25 Excluded	10.60	6.37	4.23
G-15 Excluded	10.77	6.97	3.73
G-15 Retarded A	12.92	9.53	3.39
G-15 Retarded B	11.94	9.19	2.75
G-15 Retarded C	12.09	5.37	6.72
RS-36[3] PARENT	11.46	7.19	4.27
G-50			
G-25 Excluded			
G-15 Excluded			
G-10 Excluded			
G-10 Retarded			

---

[1] Data expressed on an ash free basis

[2] Phenolic OH calculated by difference

[3] Data represents average of duplicate analyses

Figure 43. Gel filtration of DOM fractions. A. RS19 G-50; B. G-50 excluded; C. RS19 G-25; D. RS19 D-25 rerun excluded; E. RS19 G-25 excluded; F. RS19 G-25 x; G. RS19 G-25 x excluded; H. RS19 G-15; I. RS19 G-50 eluted with TRIS-HCl buffer; J. RS36A G-50; K. RS36A G-50 excluded; L. RS36A G-25; and M. RS36A G-25 excluded.

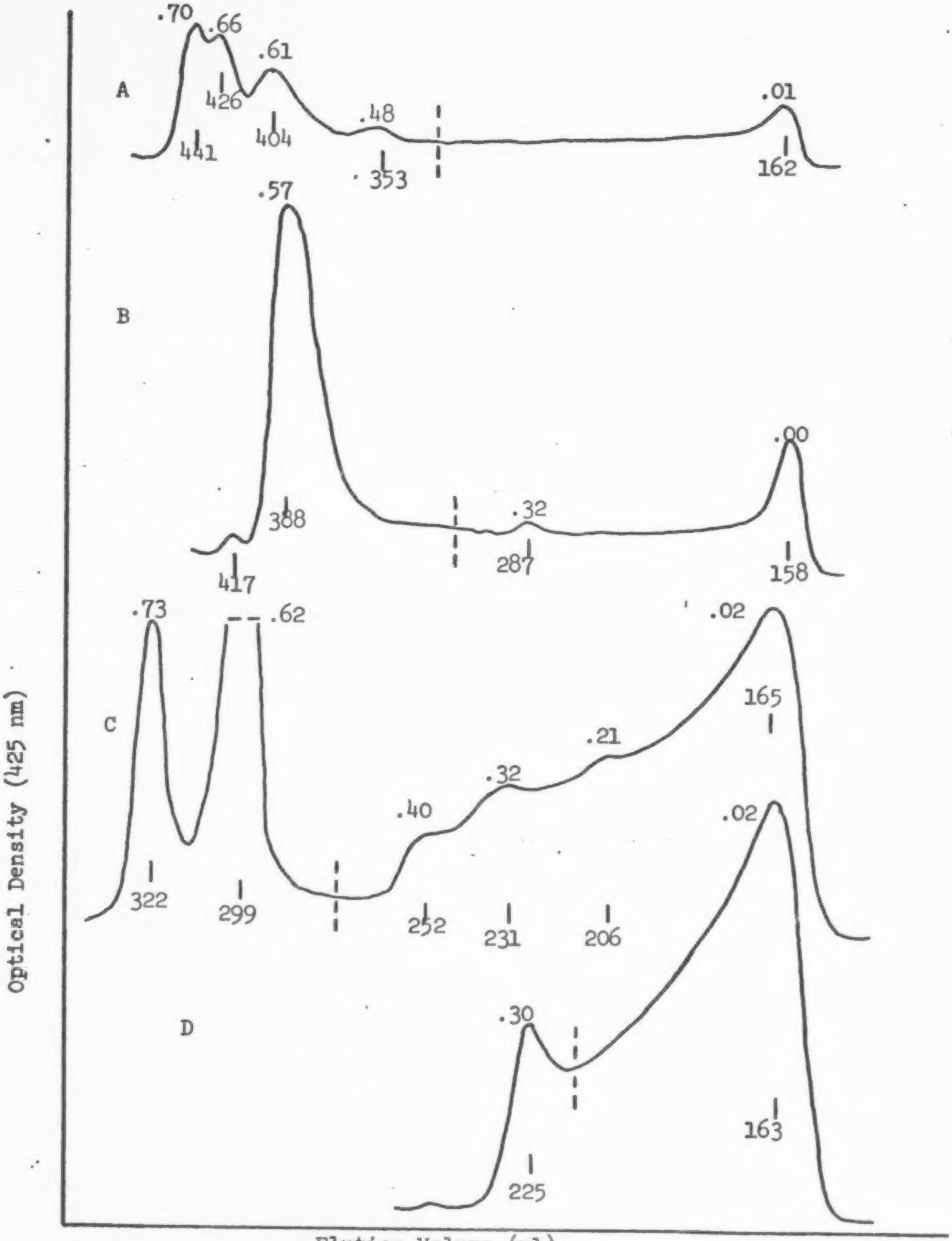

.70
.66
.61
A
426
441
404
.48
353
.01
162
.57
B
388
417
.32
287
.00
158
.73
.62
.02
C
165
.21
.32
.40
322
299
252
231
206
.02
D
.30
163
225
Optical Density (425 nm)
Elution Volume (ml)

Figure 43.

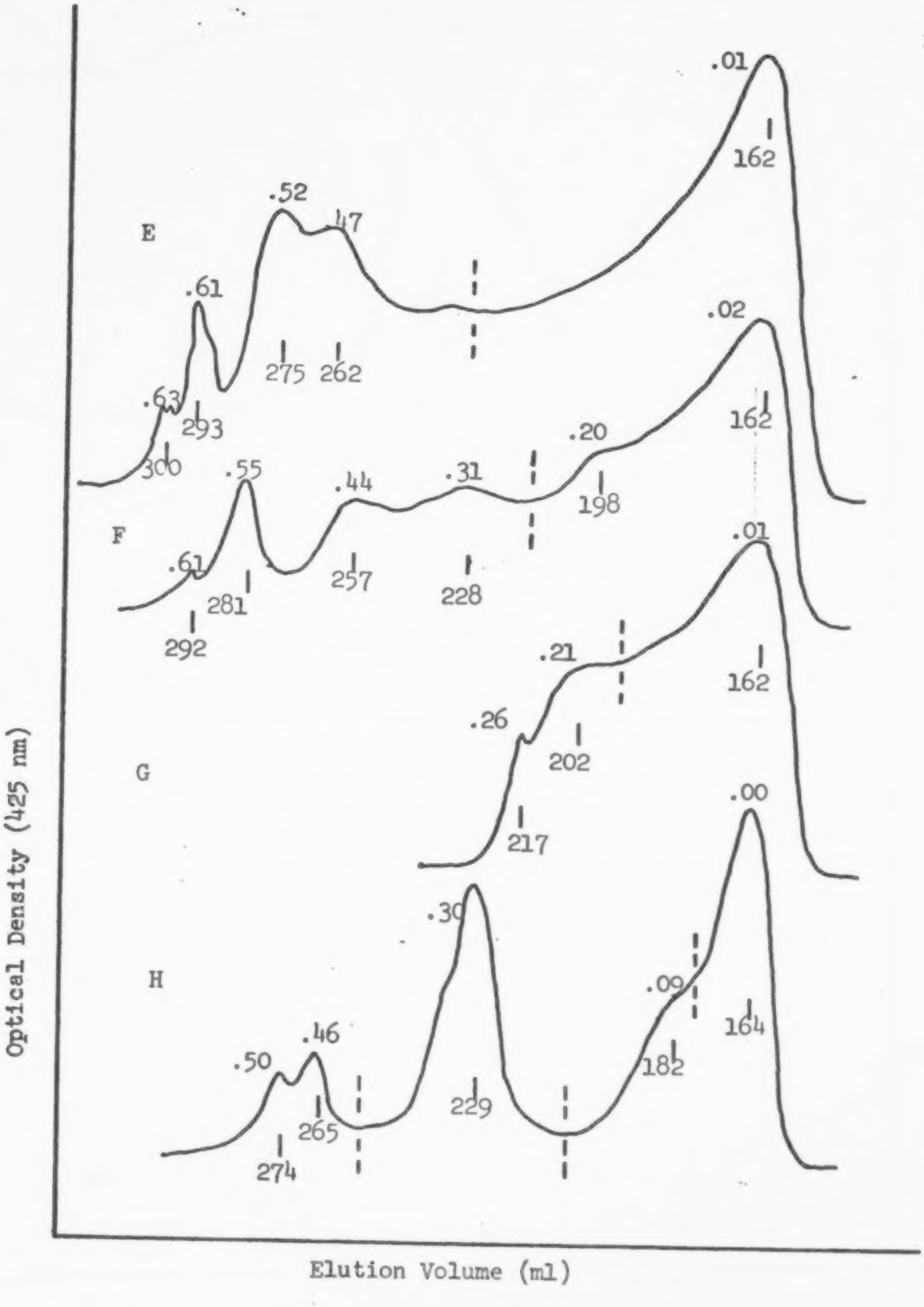


Figure 43 (continued)

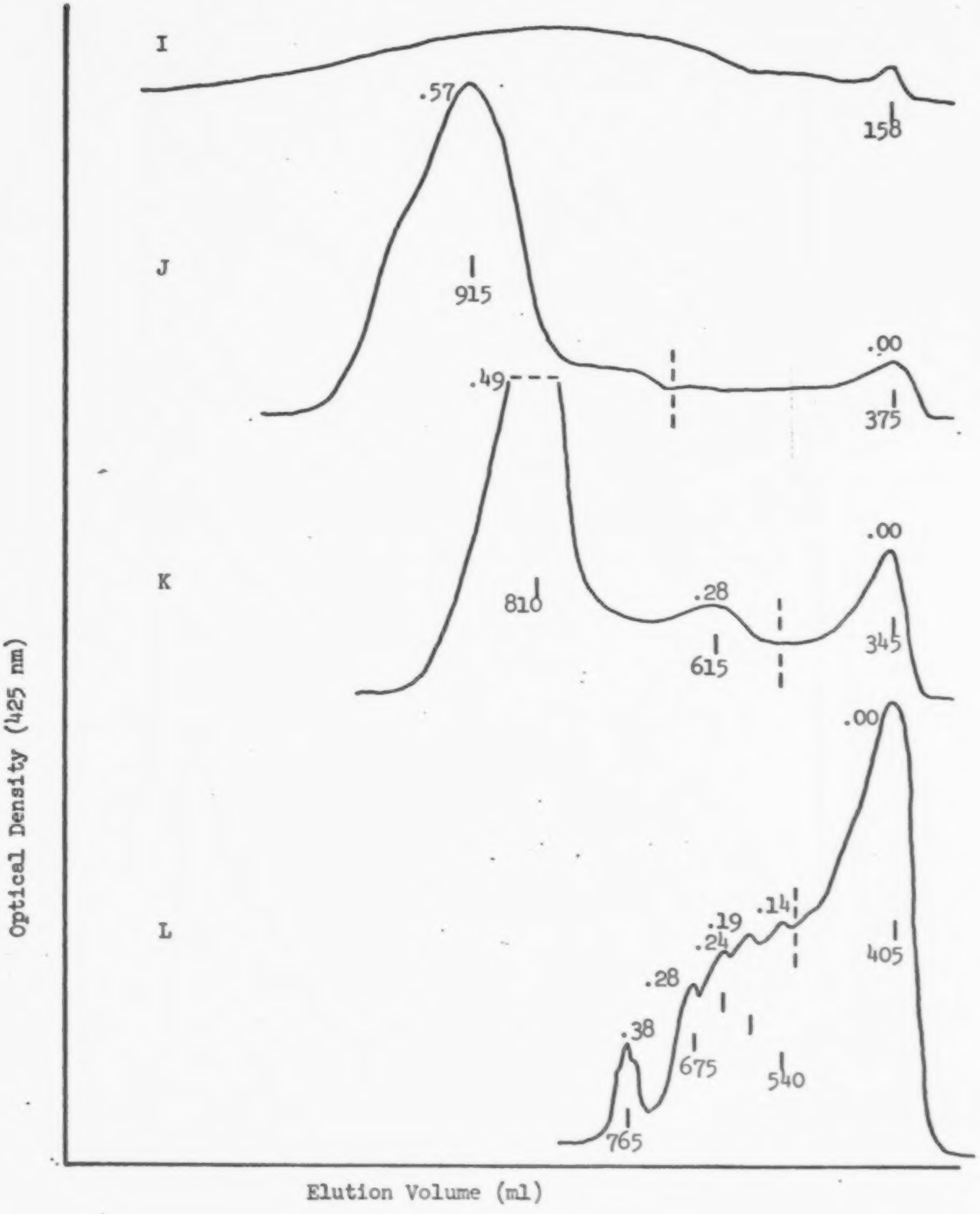


Figure 43 (continued)

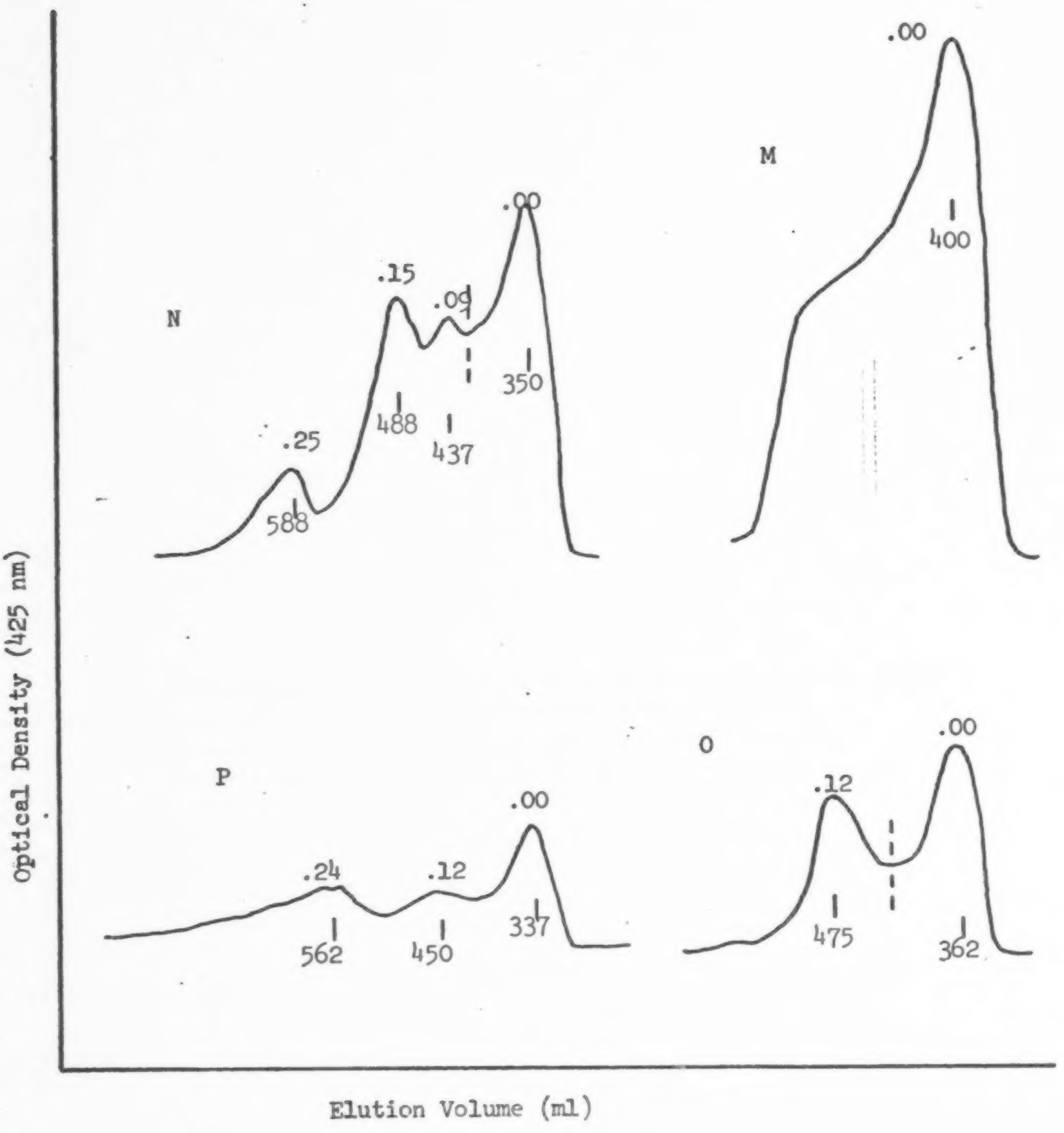


Figure 43 (continued)

Figure 44. Infrared spectra of DOM. A. RS19 G-50 excluded; B. RS19 G-25 exluded; C. RS19 G-15 excluded; D. RS19 G-15 retarded A; E. RS19 G-15 retarded B; F. RS19 G-15 retarded C; G. RS36A raw; H. RS36B raw; I. RS19; and J. RS36A.

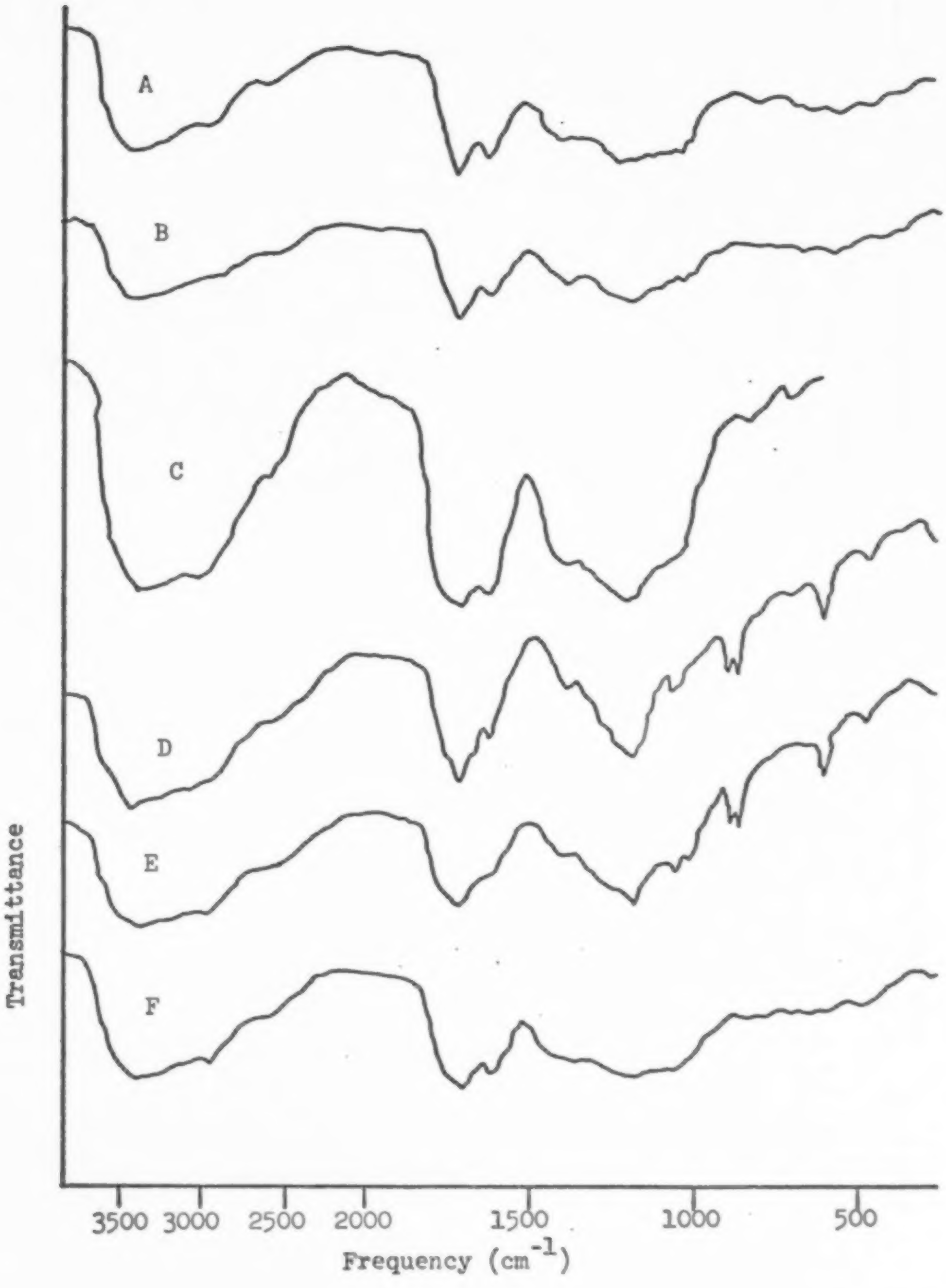

A
B
C
D
E
F
Transmittance
3500
3000
2500
2000
1500
1000
500
Frequency (cm^{-1})

Figure 44

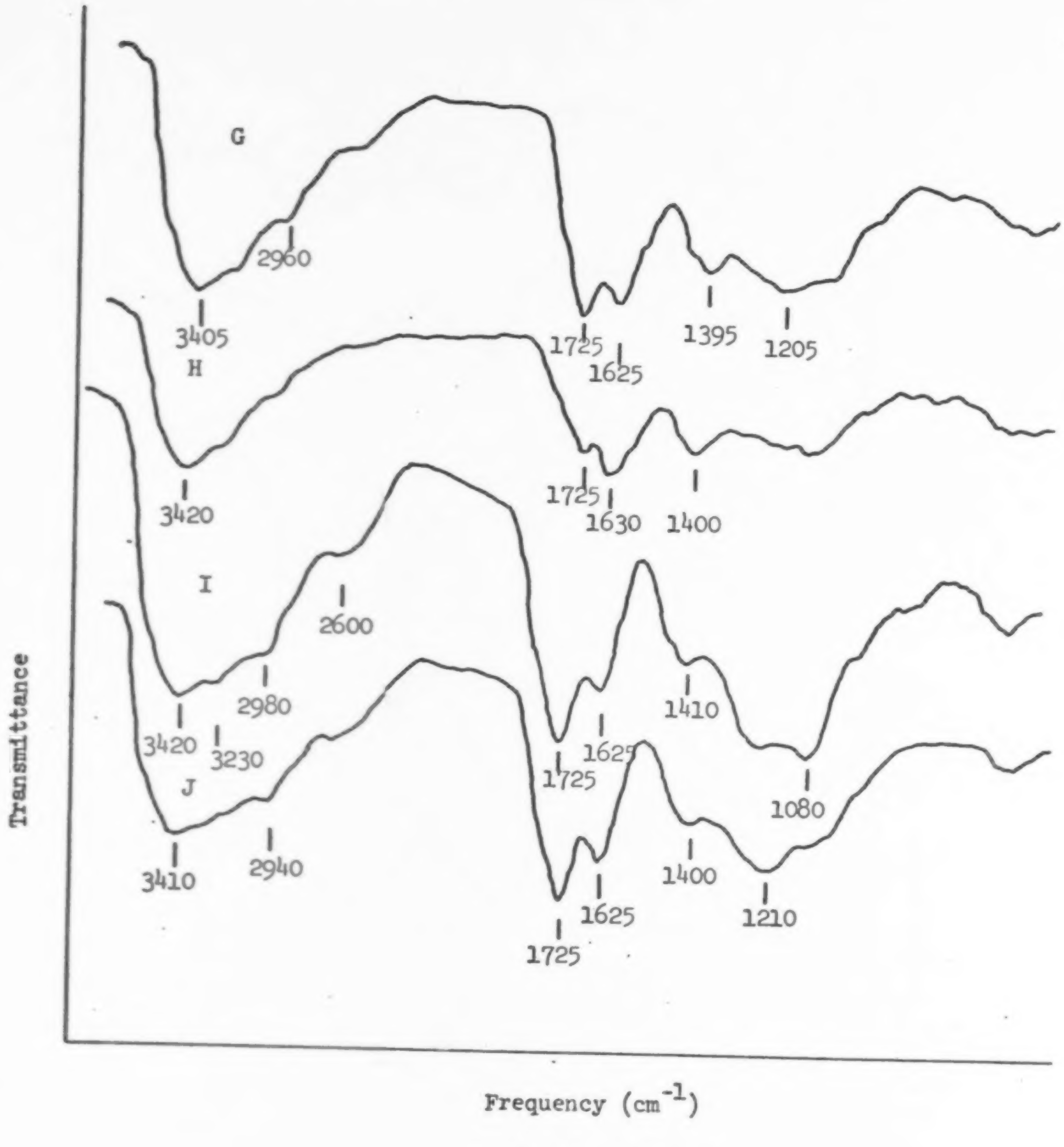


Figure 44 (continued)

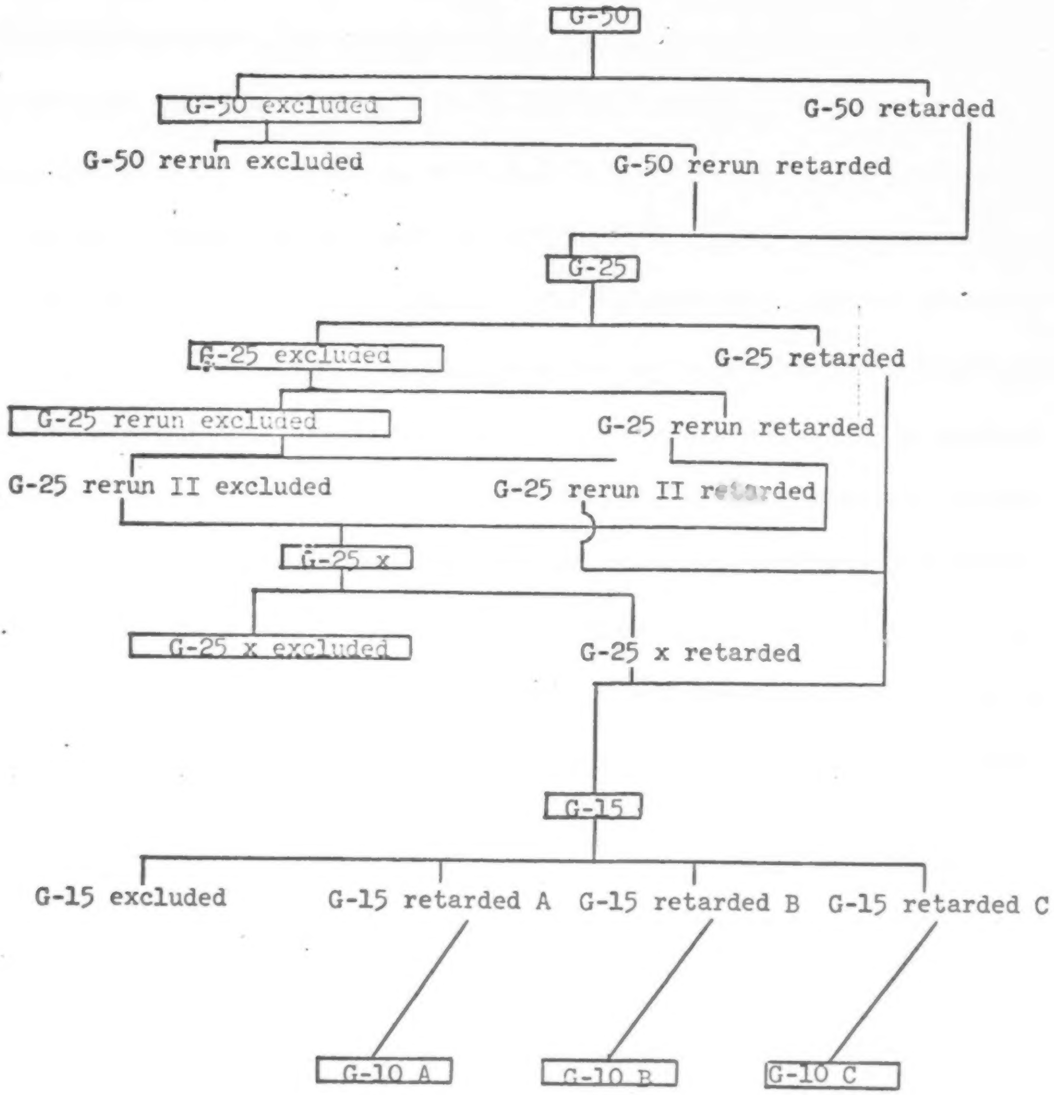

G-50
G-50 excluded
G-50 retarded
G-50 rerun excluded
G-50 rerun retarded
G-25
G-25 excluded
G-25 retarded
G-25 rerun excluded
G-25 rerun retarded
G-25 rerun II excluded
G-25 rerun II retarded
G-25 x
G-25 x excluded
G-25 x retarded
G-15
G-15 excluded
G-15 retarded A
G-15 retarded B
G-15 retarded C
G-10 A
G-10 B
G-10 C

Figure 45. Flow chart for gel filtration of RS19 on Sephadex gels.

corresponding higher oxygen percentage.

The results of our studies to date show conclusively that dissolved river water organic matter is a substance of high "environmental activity", as defined above. The high concentrations of oxygen containing functional groups enable this material to influence effectively the transport of those toxic metals which are being studied in this project. A series of analytical determinations remain to be performed: (number average) molecular weights of the individual GPC fractions (by vapor pressure osmometry), functional group analyses on the remaining samples. nuclear magnetic resonance spectroscopy as an additional independent method to determine acidic protons, and to obtain an estimate of aromatic and aliphatic proton content. All these data should then enable us to formulate a summary chemical formula for each of the fractions of dissolved river water organic matter. These data will be especially helpful in the determination of stability constants of metal-organic complexes between river water organic matter and the metals considered in this project.

B. Flocculation Studies

Field observations and results of chemical studies suggest the importance of flocculation in the estuaries of the major rivers of the southeastern Atlantic coast as a mechanism which greatly influences the fate of trace metals. In the past year laboratory studies coupled with field investigations have been carried out to elucidate the nature of this process and to characterize the flocules thus produced.

The Satilla River draining the southeastern coastal plain of Georgia contains a high degree of organic material. As the river mixes with marine waters and the salinity increases to about .1‰ floccules can be seen to form in the river. Samples of these floccules were collected near stations 1 and 4 (Figure 8) at salinities of 0.1 and 0.5‰ respectively. These were returned to the laboratory for study, and analyzed under an optical microscope. After collection the flocs continue to grow and agglomerate on the bottom of the sampling jar. The shape of individual particles is somewhat irregular, round flocs tending to be more capable of withstanding high shears. When two or more flocs gather, they clump together by a minimal point contact. The color of the flocs is a light reddish brown. Root hairs of plants are often incorporated into the flocs. Dark particles though not well distinguishable from the light brown color are also often incorporated in the flocs. Larger dark particles sometime appear independently. The majority of the flocs appear to be organic sometimes containing mineral grains.

The flocs tend to cluster together with point contacts resulting when the lowest equilibrium state is reached. Structures of the flocs in this state appear in the form of chains. The flocs comprising the chains appear as small clusters depending on the size of the individual floc. Sometimes the chains are elongated branching off in several directions. Others are curved in an array of circles or hexagons depending on the flocs. The exact structure of their arrangement is not well defined, however, the chains concentrate themselves in such a way as to form vacant holes. The flocs are sometimes clustered about a central opening, resulting in a honeycomb structure. The holes are not always vacant and the chains are far from perfect.

Analysis of the flocs showed them to contain the dominant clay minerals along with organic matter. Laboratory studies of pure clays indicate that minerals such as kaolinite and montmorillonite flocculate at around .3‰. Studies including the common organic materials (humic and fulvic acids) along with clays will be carried out to study their interaction. Ultimately the effect of flocculation on metals will be investigated.

C. Complexation of Metals by Organic Acids

The study of complexing of metals by organic acids is very important in various systems ranging from movements of complexed metal-organic through soils to the complexation and release of metals in natural waters. Zones of enrichment or leaching can be observed in soils, possibly due to selective complexing and "salting out". There are also problems encountered in complexing in natural waters, where possibly large quantities of metals can be transported downstream and then released in a suitable environment due to a change in equilibria. This aspect of our laboratory studies is directed towards the more thorough examination of the nature of the complexing in the southeastern rivers, and to obtain their thermodynamic stability constants as in contrast to conditional stability constants currently available.

The approach of this study is to obtain stability constants from potentiometric titrations with selective ion electrodes. The reaction $XM^{n+} + yL^{p-} = M_xL_y^{n-p}$ will be studied, where M is the metal ion in question, and L the complexing organic ligand. Studies of cadmium have progresses, and others are planned for lead and mercury. Stability constants K, where:

$$K = \frac{(M_xL_y^{n-p})}{(M^{n+}) \times (L^{p-})^y}$$

will be investigated. Because of the thermodynamic data obtained by the electrodes, thermodynamic constants will be obtained. The EMF and pH data obtained throughout the calculation will be evaluated by a plot of Bjerrum's formation function $\bar{n}$ vs pL, and the stability constants will be obtained from the graph. Computer programs are being developed to handle the data obtained.

Specific ion electrodes have been chosen for complex investigation because of their selectivity and thermodynamic response to the metal ions in solution. The inherent problem with this method of approach is an estimation of the concentration (or activity) of the complexing ligand. This value is currently being estimated from pH measurements, which in turn depends on a good knowledge of the organic acid. Because of the varied nature of these organic species, assumptions must be made and tested, the validity of which will be revealed in the Bjerrum plot. Results of other aspects of the total project will be of great help.

In essence, a generalized quilibrium of the form

$$HnL = nH^{+} + L^{-n}$$

must be assumed, and values of n obtained. By making estimations of the ionic strength of the system, approximations of activity can be used to obtain thermodynamic constants.

Sixty gallons of river water were obtained from County Line Branch, a tributary of the Satilla River at the junction of Brantley and Camden counties in southeast Georgia. The water was at a pH of 3.8 and dark colored, characteristic of high organic content. It originates from the swampy area in that region. This water was condensed on a rotating flash evaporator and subsequently freeze dried. 37.454 grams of organic was obtained, and was denoted RS36-B.

The organic material was desalted and an initial desalted fraction of 11.079 grams was obtained, for a 29.6% yield. The remaining organic matter was water insoluble and formed thick dark clumps in solution. This fraction was dissolved in 0.05 N NaOH, and the pH reduced to three with 2N HCl. After desalting, an excessive amount of sodium remained, and so the entire fraction was freeze-dried again and stored for future study.

The experimental apparatus has been set up and necessary titrants obtained and standardized. The readout is a digital pH meter (Orion 801) with an attached ten inch Beckman recorder. Titrations of x10^{-3}M organic matter either in 10^{-1}M Cd^{2+} or in distilled water have been completed and another titration in a solution with a background ionic strength of 0.1 will be made. Computer programs have been written to test models of complexing and to obtain thermodynamic dissociation constants. Cd data is currently being processed. These titrations are now being started for lead and mercury.

Throughout our field collecting and laboratory work we have found that the very abundant organic matter in some of the Southeastern rivers undergoes flocculation quite readily. During this process we find that some of the more abundant metals complexed with the organic matter (e.g. Fe, Al) are carried down with the organic matter. In fact, there is a close linear relation between the concentration of organic carbon and these metals in the <0.45 micron fraction of the waters. We are currently investigating this relation for much finer fractions, and will extend it to the trace metals under study. The processes of complexing and flocculation are believed to be very important in metal transport, particularly in the estuaries where much of the organic metals from the rivers is deposited.

V. TENTATIVE MODEL OF THE TRANSFER OF METALS TO AND THROUGH THE COASTAL LITTORAL-SALT MARSH ESTUARINE SYSTEM

On the basis of the results of the past year's research a tentative model for the transfer of metals to and through the system under study can be proposed. Any model of a real system must be limited in order to be manageable. In developing a model of a system it should be understood that the only reason for doing so is to obtain a better understanding of the real system. In other words, models should not be constructed of systems solely for their own sake.

Based on the knowledge of the rivers and estuaries of the coastal littoral-salt marsh system, a model can be designed which defines the major compartments of the system and their inputs and losses. Such a system is schematically presented in Figure 46. In this model the river is divided into three compartments each containing metals. As river water is transported into the estuaries, metals are potentially transferred from one compartment of the river system to various compartments of the estuarine system as indicated in the model. Once the metals are in the estuarine system in one of the various compartments, their fate there depends on the transfer to other compartments where modifications may occur to produce further transfer. Ultimately the metals must be transported out of the system by various pathways the importance of which depend on the coefficients of transfer. In the present model only the non-biologic part of the system is considered, therefore only two pathways of loss can be identified. These are, 1) loss to the marsh sediment due to sediment accumulation which is assigned the transfer coefficient K_{15}, and 2) loss in solution through offshore transport with a transfer coefficient, K_{16}. It is obvious that the offshore transport of metals could be in tissues of migrating organisms of rafted marsh grass detritus. For the present simplified model, however, the form in which the metal is transported out of the system is unimportant.

With this model, even somewhat arbitrarily constructed, a certain amount of data input can result in a better understanding of the total system. In other words, if enough of the transfer coefficients can be experimentally determined or determined on

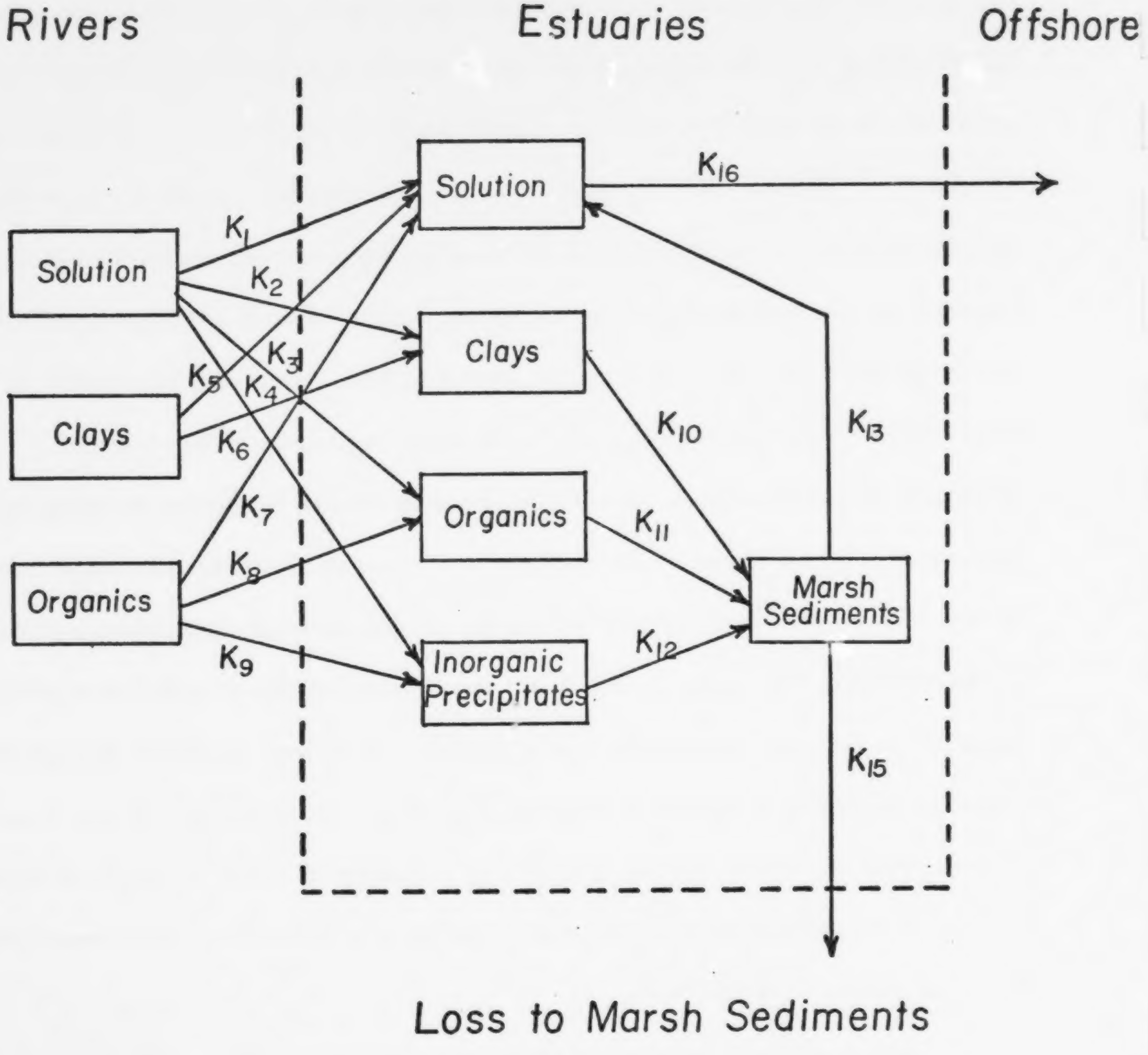

Rivers
Estuaries
Offshore
Solution
Clays
Organics
Solution
Clays
Organics
Inorganic Precipitates
Marsh Sediments
K1
K2
K3
K4
K5
K6
K7
K8
K9
K10
K11
K12
K13
K15
K16
Loss to Marsh Sediments

Figure 46. Tentative Model for the Transfer and Fate of Metal to and through the Coastal Littoral-Salt Marsh System.

the basis of field observations, then many of the transfer coefficients or pathways not lending themselves to experimental determination can be deduced. For example, if we assume that the system under consideration is in a steady state then letting Xi represent the concentration of the metals in the i compartment and K_s and K_p representing the total transfer of metals into the estuarine system in soluble and particulate forms respectively, then the following equations relating the transfer coefficients can be written:

$$K_1 = C_1 K_s \qquad K_5 = C_5 K_p$$

$$K_2 = C_2 K_s \qquad K_6 = C_6 K_p$$

$$K_3 = C_3 K_s \qquad K_7 = C_7 K_p$$

$$K_4 = C_4 K_s \qquad K_8 = C_8 K_p$$

$$K_9 = C_9 K_p$$

$$K_s + K_p = K_{15} + K_{16} \quad (1)$$

$$K_1 + K_5 + K_7 + K_{13} = K_{16} \quad (2)$$

$$K_2 + K_6 = K_{10} \quad (3)$$

$$K_3 + K_8 = K_{11} \quad (4)$$

$$K_4 + K_9 = K_{12} \quad (5)$$

$$K_{10} + K_{11} + K_{12} = K_{13} + K_{15} \quad (6)$$

when

$$\frac{dxi}{dt} = 0$$

where C_1 through C_9 are constants. Using the above sets of simultaneous equations with a certain amount of data we can begin to quantitatively define the transfer of metals to and through the modeled system.

To give an example of how this tentative model can be used, certain information can be gained on the fluxes of metals through the system using only the data that we presently have. Table 14 lists the values of several parameters which we have been able to determine from field data. Using the rates of loss of metals to sediments given in Table 10 and assuming that the area of sedimentation is that of the salt marsh estuarine environment (approximately 1 million acres) the annual fluxes of the metals to sediments have the transfer coefficients, K_{15}, as given in Table 14. Using the value of the total input of the metals into the system ($K_s + K_p$) it is possible using equation (1) to determine the flux of the metals through the estuarine system (K_{16}). Also from this model we can calculate the relative proportion of the metal input into the system which is lost in the sediment sink of the system. In Table 14 this ratio is given and indicates that the relative loss follows the order Fe > Mn > Pb > Cu > Cd > Hg. This follows the same trend as the relative rates of input of the metals to the system.

It is clear that for the data thus far obtained, there are some problems with the model. For example on the basis of the calculations resulting in the data shown in Table 14, the total loss of iron from the system is greater than that which is transported into the system by rivers. As more data for the seasonal changes of iron in the river input are obtained some of this descripency may be corrected. Also as the seasonal data are obtained we will find that some of the transfer coefficients related to the input of the metals to the estuarine system will be nonlinear, time dependent functions. Since the total volume of discharge of each river is a function of time as well, the total input of metal will have to be integrated over changes in the concentration of the metals coming in as well as changes in discharge rates.

As more field data are obtained and more experimental data are gathered the

TABLE 14

Annual Fluxes of Metals Through Tentative Model

Transfer Coefficients	10^6 Kg/yr		10^3 Kg/yr			
	Fe	Mn	Cu	Hg	Cd	Pb
K_{15}	124	0.8	44	0.3	6	68
$K_s + K_p$	57	2.3	374	4.9	63	200
K_{16}	0	1.5	330	4.6	57	132
$\frac{K_{15}}{K_s + K_p}$	> 1	0.38	0.12	0.06	0.10	0.34

model of the system can be sophisticated to take in account temporal variations in compartment concentrations and transfer rates.

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TABLE

Metal Concentration in Salt Marsh Sediments and *Spartina alterniflora*

Core # 1

								ppm											
Depth		Eh	S=	%	%	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
cm	pH	MV	MV	Moisture	TOC	T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	7.5	+15.0	-37.0	27	0.10					85		.03		4.9		8.8		20	
10	6.7	-130	-38.0	58.1	2.73					15		.07		4.9		22		67	
20	6.4	-130	-107.0	66.5	3.92		0.20		20	24	3.2	.15		2.6	1.2	30	19	84	20
30	6.5	-300	-210.0	69.5	3.99		0.20	40	28	22	2.8	.20		6.5	0.24	22	9.2	68	18
40	6.5	-340	-320.0	64.3	3.24	3.85	0.19	130	1.20	16	1.0	.14		0.6	0.3	25	19	75	1.6
50	6.7	-170	-301.0	65.0	3.16	3.98	0.18	140	24	15	2.4	.14		0.8	0.3	17	10	66	1.2
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.18	0.5	4.5	22	1.5	0.08	79
Stalks	0.19	0.6	2.0	29	<1.0	0.08	96
Roots	1.41						

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and *Spartina alterniflora*

Core # 2

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	7.2	120	12.0	48.8	2.34		0.63	350	350	20	<1.0	.14		4.6	1.0	36	1.0	110	65
10	6.8	101	2.0	25.6	1.71		0.75	230	230	16	3.1	.08		5.2	0.4	27	13	54	49
20	6.9	-76	-5.0	37.2	0.99		0.52	160	98	12	<1.0	.06		5.3	0.2	14	8.6	36	16
30	7.0	+26	-7.5																
40																			
50																			
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.15						
Stalks	0.27	0.5	4.1	27	3.9	0.04	69
Roots	0.73						

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 3

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	5.7	-80	-30	59.4	3.43	3.82	0.59	140	39	22	3.1	.12		0.6	0.3	25	13	83	35
10	4.1	+37	-45	67.5	2.38		0.62			34	2.4	.12		6.8	1.5	28	6.3	67	13
20	5.8	-300	-54	69.5	2.44		0.63		50	27	4.6	.20		3.5	0.5	21	14	65	37
30	6.5	-170	-40	65.4	2.44		0.34		31	37	2.3	.14		3.4	0.2	28	5.1	74	13
40	6.4	-130	-43	67.8	3.29		0.34	82	68	29	2.8	.12		5.7	0.2	23	2.4	59	21
50	6.5	-250	-45	68.8	3.82		0.43	180	120	29	1.9	.13		0.4	0.2	20	5.0	65	18
60	6.6	-180	-53	67.8	4.97	5.83	0.40	410	99	18	2.8	.12		0.6	0.4	13	4.9	93	18
70	6.4	-50	-67	71.6	4.30	2.17	0.24	120	91	15	1.2	.21		0.6	0.4	4.3	2.8	40	14
80	6.3	-200	-60	77.2	4.91		0.42	62	7.1	27	2.8	.31		4.5	0.2	21	5.9	58	13
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.20	1.2	4.3	27	3.7	0.16	76
Stalks	0.08	0.6	5.7	26	5.4	0.10	75
Roots	0.30						

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 4

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.8	+119	25	12	2.81		0.54	240	220	17	3.1	.05		3.8	0.8	19	11	61	27
10	6.8	+94	16	15.6	1.25		0.24	50	50	8.1	3.5	.03		3.2	0.5	16	8.1	27	11
20	6.7	+61	8	20.7	2.71		0.38		55	29	2.7	.05		1.8	0.3	21	14	104	18
30	6.6	+18	1.5	29	1.80	5.04	0.86	240	24	23	3.6	.06		0.5	0.2	23	21	93	22
40	6.5	+2	2.5	18.3	1.69		0.38	28	240	28	2.0	.04		6.3	3.0	18	20	57	13
50	6.7	-82	-2	24.7	1.58		0.34	56	75	28	3.6	.05		4.1	0.2	21	6.0	68	20
60	6.7	-105	-2.7	26.6	1.37		0.35	140	120	32	4.0	.05		2.7	2.5	18	9.9	70	21
70	6.8	-125	-3.5	25.4	1.11		0.50	240	220	36	3.1	.05		3.8	1.9	25	10	99	15
80	6.8	-213	-6.2																
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.19	0.9	8.0	45	4.4		67
Stalks	0.13	0.7	3.4	37	2.3	0.05	20
Roots	0.10						

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 5

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	7.0	+170	-30	53.6	1.78		0.45	330	331	24	2.8	.08		5.3	5.3	36	16	100	53
10	6.9	+40	-35	53.3	1.61		0.53	350	380	22	3.5	.09		2.8	2.0	33	23	67	21
20	6.9	-190	-39	58.2	1.64		0.03	230	140	21	2.8	.10		1.3		21	13	56	18
30	7.2	-210	-45	57.7	1.35		0.35	190	130	24	2.4	.09		5.6	0.3	25	13	69	20
40	7.2	-250	-48	57.0	1.72		0.39	110	28	25	3.9	.09		5.7	0.6	25	15	63	18
50	6.9	-310	-54	61.1	1.66		0.54	160	86	21	9.4	.08		4.7	2.0	28	18	64	6.0
60	7.1	-190	-53	69.3	1.41		0.38	160	120	27	1.6	.07		7.9	0.6	25	18	67	17
70	7.1	-140	-49	57.1	1.43		0.35	143	100	28	3.5	.12		1.5	0.2	26	5.8	71	9.7
80	7.1	-150	-52	58.5	1.43		0.53	210	130	28	1.6	.02		4.7	0.2	26	8.4	72	21
89	7.2	-140	-51																
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.30	0.8	2.9	20	2.7	0.07	580
Stalks	0.20	0.2	3.7	15	4.1		1100
Roots	0.61	0.5	6.0	20	7.3	0.07	580

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 6

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.6	112	+1.0	29.1	0.99		0.21		19	11	1.9	.01		0.8	0.7	23	2.3	38	7.6
10	6.4	-31	-10	38.4	1.46		0.20		7.9	11	1.2	.01		1.4	0.1	23	2.0	36	14
20	6.3	-100	-12.5	35.8	3.36		0.35	150	8.0	14	14	.02		1.2	0.3	13	4.4	39	20
30	6.4	-40	-16	19.3	1.47		0.29	150	<10	8.8	2.4	.01		0.9	0.2	15	3.6	35	<5
40	6.0	-12	-17.5	34.1	0.68		0.28	170	43	8.4	<1.0	.02		1.4	0.6	15	2.4	31	16
50	6.2	-30	-18.5	33.8	0.53		0.17	200	28	9.0	1.6	.02		0.8	0.4	14	3.2	40	10
60	6.1	-70	-18.0	32.0	0.54		0.07	120	32	5.5	1.6	.01		0.2	0.1	12	2.0	36	6.3
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.18	0.7	5.2	18	7.8	0.04	21
Stalks	0.24	0.2	2.4	13	<1.0	0.01	420
Roots	1.00	0.7	5.3	100	2.3		58

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 7

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.8	+145	-12	44.0	2.06	2.64	0.51	290	160	10	3.1	.11		0.8	0.3	21	13	120	68
10	6.7	+60	-24	28.3	0.71	1.30	0.25	84	40	2.0	<1.0	.03		<0.1	0.4	4.1	3.6	69	40
20	6.9	+40	-25.5	21.3	0.38	0.51	0.08	95	28	4.2	1.9	.01		0.4	<0.10	5.3	1.9	7.9	7.5
30	7.3	-240	-41.0	19.3	0.59	0.24	0.05	86	21	<1.0	2.1	.01		<0.1	<0.10	5.3	3.2	5.9	4.7
40																			
50																			
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.19	0.5	4.1	31	3.2	0.07	31
Stalks	0.21	0.5	2.9	33	7.0	0.03	82
Roots	1.16	1.0	5.5	25	3.0		39

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 8

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.4	-250	-115	43.9	2.08	2.43	0.08	160	16	8.8	2.0	.04		0.4	0.6	6.4	4.0	38	10
10	6.5	-300	-125	35.8	1.99	1.91	0.10	130	20	4.0	2.8	.02		<0.1	0.2	14	1.0	18	4.0
20	6.6	-290	-165	38.4	1.32	1.97	0.08	100	79	3.9	3.5	.02		0.5	0.1	8.8	6.1	20	<1.0
30	6.5	-240	-220	28.5	0.50	1.63	0.28	99	16	6.0	<1.0	.01		0.6	0.2	16	1.0	18	9.9
40	6.0	-360	-205	30.3	0.56	2.11	0.11	110	15	3.0	2.3	.01		3.1	0.2	5.0	4.2	22	12
50	6.7	-320	-220	21.2	0.16	0.71	0.62	83	28	<1.0	<1.0	.01		0.2	0.3	3.8		9.9	4.3
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.31	0.4	3.7	19	7.0	0.10	17
Stalks	0.22	0.3	2.3	29	3.4	0.06	30
Roots	0.77	0.6	4.4	47	5.0		46

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 9

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.5	-70	-12	41.6	4.28	2.19	0.19	200	30	66	3.6	.02		0.3	0.1	16	4.9	56	22
10	6.4	-20	-26	60.0	5.02	4.84	0.02	230	48	7.7	2.0	.05		12	2.2	14		14	18
20	6.3	-110	-31	66.1	4.80	4.28	0.16	220	60	10	4.4	.03		0.6	0.8	12	11	53	17
30	6.3	-170	-37	65.2	2.84	4.46	0.10	380	130	13	<1.0	.06		1.0	0.5	25	4.9	65	16
40	6.3	-250	-64	66.7	3.55	4.32	0.55	290	140	6.9	2.7	.03		0.9	0.7	17	8.2	43	17
50	6.3	-290	-73	63.1	3.15	5.71	0.66	480	167	8.3	2.3	.03		0.9	0.2	14		63	18
60	6.4	-310	-91	59.5	2.01	4.20		370	120	10	2.6	.05		1.6	0.2	11	4.7	53	11
70	6.5	-330	-104	60.9	2.00	3.61	0.34	360	130	12	<1.0	.03		1.0	0.6	2.2	6.8	56	9.9
80	6.4	-340	-146	57.3	2.11	3.37	0.40	250	87	15	2.4	.09		1.0	0.4	7.3	4.0	55	<5.0
~~90~~ 88	6.5	-360	-179																
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.10	0.4	5.0	19	10	0.07	39
Stalks	0.12	0.4	3.1	23	4.8	0.14	43
Roots	0.71	0.4	2.5	29	8.0		37

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and *Spartina alterniflora*

Core # 10

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm									
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.0	-45	0	32.5	0.53	0.91	0.32	110	73	6.3	<1.0	.04		<0.1	<0.1	6.5	6.1	16	10
10	5.8	-58	+25	51.3	0.69	1.03	0.25	87	160	4.0	3.1	.04		<0.1	<0.1	7.9	7.7	18	<5.0
20	6.0	-62	-80	34.5	0.69	8.63	0.08	40	<10	2.0	<1.0	.05		<0.1	<0.1	2.8	2.0	9.9	<5.0
30	6.3	-72	-180	25.4	8.56	0.16	0.13	790	16	<1.0	<1.0	.04		<0.1	<0.1	<1.0	<1.0	7.9	<5.0
40	6.1	-87	-50	20.4	0.26	0.2	0.06	7.9	9.8	<1.0	<1.0	.03		<0.1	<1.0	<1.0	<1.0	5.9	<5.0
50	6.1	-82	-160	18.4	0.24	0.24	0.04	7.9	3.8	<1.0	<1.0	.01		0.2	<0.1	4.3	4.0	5.0	<5.0
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.20	0.4	5.4	29	5.7	0.19	32
Stalks	0.11	0.4	2.2	17	5.6	0.02	19
Roots	0.82	0.9	2.4	53	8.4	0.12	54

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 11

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.2	-210	-60	79.4	11.8	1.31		75		10	<1.0	.10		0.6	0.7	9.7	6.1	28	
10	6.4	-260	-96	74.3	6.9	2.12	0.11	120	36	12	<1.0	.08		0.4	0.7	8.9	2.0	56	9.9
20	6.4	-330	-249	49.2	1.9	2.05	0.15	63.5	20	5.6	<1.0	.04		<0.1	0.6	13	2.4	28	9.9
30	6.4	-350	-390	54.2	1.4	3.18	0.09	200	20	7.1	< 1.0	.06		<0.1	0.4	14	3.2	49	<1.0
40	6.5	-370	-470	61.5	2.6	4.27	0.28	240	44	9.9	<1.0	.05		1.0	0.7	5.5	5.2	87	18
50	6.6	-390	-505	47.8	1.2	2.46	0.09	190	16	6.6	2.4	.04		<0.1	1.0	10	3.2	200	12
60	6.5	-400	-510	33.3	0.5	1.51	0.20	170	47	5.6	<1.0	.03		1.0	0.8	8.1	7.4	24	3.9
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.14	0.5	4.6	13	1.8	0.03	340
Stalks	0.13		2.1	54	47	0.12	54
Roots	1.40	0.5	4.6	13	43	0.11	280

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 12

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.3	-270	-60	44.1	1.6	4.49	0.33	250	58	19	<1.0	.07		1.6	0.8	15	15	89	31
10	6.7	-290	-140	75.7	2.8	3.48	0.19	140	78	13	2.7	.12		0.7	0.4	13	4.3	53	14
20	6.6	-310	-230	75.4	2.4	5.64	0.32	320	100	17	2.4	.12		<0.1	0.5	13	12	84	12
30	6.7	-360	-390	74.6	2.7	4.70	0.28	230	60	8.7	1.6	.08		0.6	0.5	19	6.6	69	<5.0
40	6.7	-370	-440	43.8	3.3	5.14	0.31	250	55	9.6	<1.0	.04		<0.1	0.5	15	4.3	62	<5.0
50	6.7	-380	-465	70.4	3.3	5.51	0.43	350	110	10	2.4	.10		0.8	0.7	16	4.3	66	18
60	6.7	-380	-470	81.9	3.5	4.53	0.50	290	120	9.5	<1.0	.11		0.6	0.4	22	6.2	67	<5.0
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.19	0.6	6.1	21	6.4	0.21	49
Stalks	0.23	0.6	2.6	18	2.9	0.10	55
Roots	1.11	0.6	13	42	5.4		51

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 13

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	5.7	-80	-30	63.1	3.9	4.36	0.31	190	33	17	5.7	.11		1.3	0.7	24	19	79	43
10	6.6	-220	-100	66.3	3.9	5.90	0.19	350	48	21	7.4	.12		1.0	0.3	25	10	97	30
20	6.5	-230	-189	73.5	4.5	4.19	0.32	380	1000	16	3.8	.26		1.2	0.3	20	6.6	77	29
30	6.5	-320	-470	70.9	3.8	4.80	0.27	510	880	30	3.2	.24		1.1	0.3	19	14	99	32
40	6.6	-390	-495	68.0	2.1	4.86	0.74	420	200	24	<1.0	.19		0.4	0.7	24	12	87	54
50	6.6	-430	-530	66.9	2.9	5.02	0.55	390	190	17	<1.0	.15		<0.1	0.8	13	9.9	73	16
60	6.6	-420	-560	69.7	3.0	3.82	0.53	350	170	19	7.9	.10		1.3	1.1	21	3.6	71	20
70	6.6	-420	-560	68.2	2.4	3.41	0.31	340	89	15	<1.0	.09		<0.1	0.2	24	9.9	67	<5.0
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.26	0.3	6.2	21	6.4	0.21	49
Stalks	0.26	0.3	3.8	19	4.6	0.05	38
Roots	0.22	1.0	4.0	20	6.3		29

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 14 (IDOE II)

								ppm											
Depth		Eh	S=	%	%	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
cm	pH	MV	MV	Moisture	TOC	T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.7	30	+17	64.24	2.7	4.15	0.52	380	250	13	<1.0	.11		<0.1	0.7	32	13	93	16
10	6.7	-85	+15	65.29	3.5	2.76	0.01	210	40	10	2.0	.12		0.2	1.0	26	4.6	34	<1.0
20	7.0	-75	-10	62.03	2.7	3.9	0.10	230	160	12	2.0	.15		<0.1	<0.1	27	8.7	69	<1.0
30	6.7	-85	-10	62.16	2.2	3.42	0.08	210	40	9.8	1.6	.14		0.5	<0.1	14	3.0	61	1.2
40	6.7	-210	-25	63.36	2.1	3.92	0.33	690	300	13	1.6	.12		1.0	0.3	14	9.3	75	56
50	6.8	-300	-50	63.27	1.7	3.89	0.36	340	110	11	<1.0	.06		0.6	0.5	11	5.6	55	22
60	6.9	-340	-80	62.80	2.0	2.37	0.33	220	96	9.1	1.9	.08		0.2	0.3	21	9.4	38	<1.0
70	6.9	-350	-140	63.58	1.8	3.22	0.39	340	200	8.9	3.2	.07		0.7	0.3	16	7.1	55	<1.0
80	7.2	-330	-240	63.62	2.3	2.66	0.42	250	130	5.8	3.2	.06		0.6	0.2	23	19	34	20
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves							
Stalks							
Roots							

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 15 (IDOE - 1)

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm Mn		ppm Cu		ppm Hg		ppm Cd		ppm Pb		ppm Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	5.8	-10	-35	64.38	5.2	2.52	0.55	180	82	11	2.0	.15		<0.1	0.4	23	9.8	63	23
10	5.9	-120	-35	65.19	4.1	2.81	0.11	170	78	12	1.6	.10		1.2	<0.1	15	5.4	75	20
20	6.0	-110	-35	62.63	2.3	4.63	0.80	210	84	15	<1.0	.09		0.7	1.0	29	15	67	40
30	6.0	-50	-40	68.16	2.9	3.18	0.57	110	75	12	3.6	.16		0.8	0.4	16	10	49	28
40	6.1	-40	-40	65.72	3.9	3.88	0.69	150	67		3.2	.07		0.4	0.2	21	17	69	30
50	5.9	-145	-50	64.23	2.6	3.63	0.19	190	78	11	<1.0	.09		1.0	0.4	13	6.3	53	18
60	5.9	-240	-50	65.86	4.2	3.09	0.37	120	71	4.4	<1.0	.12		0.8	0.1	9.5	6.3	36	7.8
70	6.1	-200	-40	65.01	.8	4.75	1.1	130	88	5.1	<1.0	.10		0.6	0.8	19	11	85	44
80	6.0	-260	-27	63.07	1.3	6.39	0.54	200	80	10	2.3	.09		1.2	0.6	21	11	63	24
90	6.0	-240	-15	62.60	1.6	5.06	0.49	270	18	11	2.0	.08		1.0	0.8	18	11	81	27
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves							
Stalks	NO SAMPLE						
Roots							

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 16

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.5	+20	-40	38.2	0.78	2.93	0.23	830	530	8.9	1.2	.05		0.8	0.4	17	7.2	52	1.0
10	6.4	+20	-60	57.0	1.10	2.82	0.21	300	180	8.1	2.4	.02		0.7	0.7	17	7.7	37	24
20	6.4	+40	-69	56.0	1.03	3.20	0.30	330	120	10	<1.0	.02		0.8	0.8	15	5.4	53	19
30	6.3	+40	-67	22.6	0.52	1.42	0.15	280	110	8.5	<1.0	.01		1.6	0.8	14	3.1	59	9.7
40	6.4	+20	-63	46.3	0.21	3.34	0.11	230	76	8.1	2.4	.02		0.8	0.6	18	9.9	49	28
50	6.3	+40	-60	87.2	0.27	2.92	0.17	230	79	3.6	1.6			0.6	0.9	2.0	11	47	<1.0
60	6.3	-60	-60	48.1	0.29	3.03	0.20	220	40	5.7	3.1			0.8	0.3	20	11	43	39
70	6.2	-30	-60	48.7	0.62	2.87	0.16	210	67	9.1	3.2			0.2	0.6	21	11	32	1.4
80	6.5	+60	-62	46.7	0.97	3.38	0.30	670	380	13	1.6			0.8	0.2	15	9.1	65	1.0
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.37	0.4	5.7	8.0	6.8	0.08	140
Stalks	0.24	0.2	3.8	170	2.0	0.07	100
Roots	0.40						

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 17

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe T	% Fe L	Mn T	Mn L	Cu T	Cu L	Hg T	Hg L	Cd T	Cd L	Pb T	Pb L	Zn T	Zn L
								ppm											
0	6.0	-80	-100	35.2	0.62	1.40	0.17	230	120	2.8	2.7	.02		0.7	0.2	22	11	20	19
10	6.0	-140	-139	40.9	0.69	1.44	0.18	200	18	5.7	<1.0	.03		<0.1	1.0	13	<1.0	24	9.9
20	6.0	-140	-250	45.2	1.04	3.00	0.32	210	27	6.5	<1.0	.07		<0.1	1.0	22	12	42	11
30	6.1	-70	-230	60.8	1.85	3.90	0.38	240	48	12	1.2	.05		0.2	<0.1	21	8.2	55	<5.0
40	6.2	-230	-220	58.8	1.63	2.40	0.30	200	59	6.5	<1.0	.02		<0.1	0.4	21	5.0	43	9.9
50	6.2	-200	-208	60.6	1.96	3.60	0.42	380	97	6.0	<1.0	.05		<0.1	0.2	21	<1.0	54	<5.0
60	6.2	-250	-190	57.3	1.31	3.20	0.52	56	320	6.5	2.7	.09		<0.1	0.6	19	9.2	50	20
70	6.2	-220	-185	55.5	2.21	2.56	0.23	400	160	6.7	<1.0	.04		0.7	0.4	18	4.2	43	130
80	6.2	-190	-180	61.2	2.45	2.91	0.28	440	200	5.7	<1.0	.05		<0.1	<0.1	19	14	51	24
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.33	0.3	5.4	46	2.0		700
Stalks	0.09	0.2	3.1	14	1.5	0.04	21
Roots	0.52	0.3	4.0	28	1.0		51

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 18

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.1	+100	-45	64.3	3.82	2.36	1.07	610	390	15	1.9	.28		0.8	0.5	26	9.2	61	39
10	6.3	+ 30	-55	65.4	3.88	2.60	0.46	140	76	11	2.3	.12		0.5	0.3	21	8.1	35	34
20	6.4	- 80	-57	66.3	3.78	3.40	0.22	250	86	15	1.9	.15		0.6	0.6	33	11	61	34
30	6.5	-130	-65	66.1	6.75	5.07	0.39	300	200	11	1.2	.15		0.1	0.3	17	11	89	31
40	6.6	-160	-73	65.5	3.74	4.47	0.21	190	210	14	0.9	.17		0.2	0.3	28	14	84	25
50	6.7	-270	-93	62.8	3.60	2.40	0.25	200	150	6.1	0.5	.16		0.7	0.3	18	11	38	20
60	6.8	-240	-101	65.1	3.52	2.40	0.08	220	140	15	1.2	.09		2.4	0.4	25	12	57	22
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.07	1.1	3.5	25	2.9	0.14	50
Stalks	0.08	0.2	4.1	28	6.8	0.06	45
Roots	0.43	1.5	5.4	32	3.4	0.14	50

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 19

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.2	+160	-45	39.4	1.41	2.15		230	110	5.2	0.9	.03		<0.1	0.3	16	4.4	50	51
10	6.3	+100	-60	28.0	0.72	0.90	0.08	170	17	3.1	0.5	.04		0.2	0.6	12	<1.0	15	9.7
20	6.4	+80	-67	25.4	0.57	0.90	0.08	130	13	2.8	0.5	.03		<0.1	0.4	11	<1.0	12	21
30	6.5	+40	-68	24.7	0.61	0.86	0.10	120	28	5.9	1.5	.01		0.5	0.6	12	1.3	<5.0	23
40	6.4	+40	-74	37.4	1.19	1.63	0.20	390	48	5.5	0.9	.02		8.6	0.3	16	4.9	30	59
50	6.8	+30	-82	27.4	0.60	0.56	0.12	88	24	<1.0	0.9	.03		<0.1	0.3	4.2	<1.0	<5.0	4.3
60	6.6	+20	-81	26.4	0.19	0.70	0.20	94	13	3.4	1.2	.01		1.8	1.2	8.9	<1.0	<5.0	8.4
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.22	0.4	4.2		3.6		
Stalks	0.28	0.3	2.4	15	4.0	0.04	38
Roots	0.52	0.9	5.4	53	8.0		

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 20

Depth		Eh	S=	%	%	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
cm	pH	MV	MV	Moisture	TOC	T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.4	-370	-165	65.3	2.75	4.10	0.26	210	84	9.0	0.5	.06		1.1	0.4	15	7.1	55	8.3
10	6.3	-350	-350	66.9	2.39	3.30	0.22	180		7.9	0.5	.06		0.7	0.3	16	7.9	39	
20	6.4	-290	-440	68.4	2.68	4.00	0.35	200	85	9.2	1.5	.03		0.8	0.6	17	9.6	46	32
30	6.4	-320	-405	66.2	2.97	3.40	0.08	200	100	7.3	0.2	.12		0.7	0.4	16	7.6	31	19
40	6.4	-340	-475	68.1	3.56	6.16	0.28	230	110	7.2	0.9	.06		0.7	0.4	13	4.9	76	30
50	6.4	-330	-470	67.4	3.95	4.30	0.50	140	69	5.5	1.2	.03		1.8	0.3	12	8.9	29	35
60	6.4	-380	-483	71.4	8.33	2.10	0.22	92	33	4.8	0.5	.03		0.6	0.3	13	11	15	58
70	6.5	-340	-495	73.5	5.63	3.32	0.14	140	40	8.4	0.2	.04		<0.1	0.3	21	4.9	60	48
80	6.5	-220	-492	70.0	7.98	2.60		120	22	14	0.2	.10		1.0	0.3	16	7.0	35	6.9
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.62	1.9	2.9	13	1.8	0.04	550
Stalks	0.09	0.4	2.1	12	1.9	0.02	36
Roots	0.13	0.3	2.5	85	5.8		32

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 21

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.3	-50	+8	52.8	4.12	2.3	0.25	280	72	12	0.5	.08		0.9	0.3	24	10	37	17
10	6.1	-170	-10	54.7	4.75	1.6	0.16	150	56	7.9	0.9	.11		0.4	0.3	9.4	15	21	54
20	6.3	-100	-20	47.7	1.11	3.86	0.11	200	55	6.0	0.2	.06		<0.1	0.3	2.2	9.3	28	15
30	6.4	-50	-25	60.0	6.00	3.7	0.20	270	110	8.4	0.9	.08		2.3	0.6	13	12	34	56
40	6.4	-210	-35	68.7	10.5	4.1		290	150	7.4	0.9	.03		2.5	1.8	14	11	66	75
50																			
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.07	0.4	3.3	19	2.6	0.05	19
Stalks	0.28	0.1	2.7	23	2.8	0.03	580
Roots	0.40	0.4	4.2	87	8.1		54

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 22

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	4.9	+70	-47	78.7	14.2	1.6	.02	43	1.0	12	0.2	.14		1.5	0.1	10	2.2	25	11
10	6.0	-180	-72	76.0	11.0	2.0	0.02	42	31	8.1	0.2	.08		1.0	0.2	16	12	25	8.2
20	6.1	-300	-250	75.4	11.2	4.2	0.44	64	51	7.2	0.2	.04		0.3	0.3	9.5	8.0	15	15
30	6.0	-320	-260	77.2	10.7	6.14	0.42	160	51	7.1	0.2	.09		0.4	0.3	10	8.0	63	15
40	6.1	-220	-428	70.8	4.16	4.1	0.43	130	58	4.1	1.6	.03		0.7	0.3	12	2.2	35	14
50	6.2	-220	-460	67.8	3.71	9.5	0.36	170	35	9.5	1.6	.06		1.0	0.3	22	3.6	71	15
60	6.2	-250	-480	68.2	3.13	1.5	0.18	150	46	1.5	0.9	.03		0.6	0.3	12	1.3	3.5	14
70	6.3	-290	-470	67.7	2.83	4.5	0.18	220	51	4.5	0.9	.03		0.9	0.3	10	4.0	47	210
80	6.3	-340	-510	71.1	5.19	8.7	0.17	210	58	8.7	0.9	.03		0.6	0.5	19	1.8	62	54
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.22	1.9	2.9	13	1.8	0.04	550
Stalks	0.20	0.4	2.1	12	1.9	0.02	36
Roots	0.21	0.3	2.5	85	5.8		32

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 23

Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		ppm											
								Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.0	+160	-37	59.8	2.75	2.8	0.28	220	13	10	2.6	.05		0.4	0.4	25	9.7	40	7.0
10	6.1	+140	-49	58.7	2.63	2.9	0.20	38	4.0	6.0	1.2	.10		0.6	0.2	14	4.9	23	30
20	6.2	+90	-59	59.5	2.21	2.7		120	6.2	10	0.9	.10		0.7	0.1	23	7.2	37	7.0
30	6.3	+90	-62	61.9	2.75	3.47	0.04	140	4.0	15	1.2	.08		1.4	0.1	14	3.1	76	14
40	6.3	+40	-61	57.0	3.46	1.4	0.18	97	11	8.4	1.2	.07		1.0	0.3	19	6.2	24	23
50	6.5	+70	-64	61.7	3.69	4.2	0.22	150	67	10	1.9	.10		0.2	0.5	24	4.4	72	52
60	6.4	+70	-67																
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.69	0.4	3.7	13	3.2	0.05	310
Stalks	0.22	0.1	3.1	21	3.8	0.08	550
Roots	0.50	0.4	2.6	46	6.9	0.02	24

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 24

								ppm													
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.5	+180	-10	35.8	2.66	1.2	0.12	230	67	6.1	1.2	.06		0.4	0.2	17	4.5	27	15
10	6.5	+170	-18	25.0	3.62	0.58	0.12	180	45	3.0	1.2	.04		1.1	0.3	13	1.8	15	1.0
20	6.9	+175	-20																
30	7.0	+175	-21																
40	6.8	+150	-20																
50																			
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.26	0.2	3.6	18	2.9	0.05	350
Stalks	0.33	0.3	2.5	21	0.5	0.08	550
Roots	0.16	0.6	2.8	67	3.9	0.09	67

T = Total Sediment

L = Leached

TABLE

Metal Concentration in Salt Marsh Sediments and Spartina alterniflora

Core # 25

								ppm											
Depth cm	pH	Eh MV	S= MV	% Moisture	% TOC	% Fe		Mn		Cu		Hg		Cd		Pb		Zn	
						T	L	T	L	T	L	T	L	T	L	T	L	T	L
0	6.1	+20	-35	26.4	0.68	1.39	0.10	56	1.0	1.0	2.9	.03		0.4	0.1	4.4	1.0	9.0	1.0
10	6.1	-180	-50	30.7	0.69	1.6	0.16	60	1.0	1.5	0.5	.01		0.6	0.1	12	1.0	10	1.0
20	6.1	-180	-60	42.5	1.51	1.9	0.09	77	1.0	1.9	0.9	.05		0.1	0.1	12	1.0	15	50
30	6.2	-180	-76	39.2	1.29	1.4	0.16	66	13	1.0	1.2	.05		0.4	0.1	11	1.0	10	170
40	6.1	-280	-75	52.5	2.76	1.71	0.08	63	1.0	4.3	0.2	.04		0.9	0.2	6.3	1.0	18	67
50	6.2	-200	-90	63.3	4.35	1.2	0.08	120	1.0	4.1	2.2	.14		0.1	0.3	11	9.5	27	49
60																			
70																			
80																			
90																			
100																			

SPARTINA

	Hg	Cd	Pb	Zn	Cu	Fe %	Mn
Leaves	0.15	0.5	3.4	9.8	1.4	0.01	12
Stalks	0.18	0.1	1.1	12	1.0	0.01	550
Roots	0.42	0.6	3.6	39	0.3	0.12	39

T = Total Sediment

L = Leached

Sediment Sample Description List

1. Clay
2. Clay
3. Silty clay
4. Silty clay with fine grained sand
5. Silty clay
6. Clay
7. Silty clay
8. Clayey, silty fine grained sand
9. Clayey, medium grained sand with shell fragments
10. Silty clay with gravel and large shell fragments
12. Slightly clayey fine-medium grained sand
13. Slightly clayey medium grained sand
15. Medium grained sand with few shell fragments
16. Silty clay
17. Silty clay
18. Slightly silty clay
19. Clayey, silty sand with few shell fragments
20. Slightly silty clay
21. Clayey, gravely sand
22. Clayey silt

Clay Mineralogy of Salt Marsh Sediments
(Under 2 m size fraction)

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonit (%)
1	15	61	7	32
	25	56	0	44
	35	49	6	45
	45	59	7	34
	55	71	0	29
	Average	59	4	37
2	2	37	33	30
	15	61	10	29
	25	50	18	32
	Average	49	20	30
3	2	81	4	15
	15	78	5	17
	25	69	17	14
	35	79	10	11
	45	76	0	24
	55	51	11	38
	65	71	2	27
	75	64	0	36
	85	67	5	27
	Average	71	6	23
4	0	66	0	34
	15	55	19	26
	25	64	0	36
	35	70	6	24
	45	72	2	26
	55	80	0	20
	65	70	7	23
	Average	68	5	27
5	15	57	0	42
	25	59	5	35
	35	51	4	45
	45	51	10	39
	55	60	7	33
	65	58	2	40

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonite (%)
5	75	62	2	36
	85	61	3	36
Average		57	4	39
6	2	53	6	41
	10	55	9	36
	20	60	9	32
	30	38	15	46
	40	37	6	57
	50	32	3	65
	60	37	5	57
Average		45	8	47
7	0	56	2	40
	10	30	3	47
	20	40	6	54
Average		42	4	54
8	2	43	11	46
	15	41	4	55
	25	46	3	51
	35	37	1	61
	45	32	8	60
	55	46	6	47
Average		41	6	53
9	2	33	11	56
	15	51	2	47
	25	48	4	48
	35	47	2	52
	45	37	1	66
	55	34	4	62
	65	35	3	62
	75	34	6	59
	85	46	6	48
Average		41	4	55

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonit (%)
10	2	36	2	61
	25	49	4	47
	35	50	10	40
	55	36	6	60
Average		43	6	51
11	2	56	18	26
	15	42	22	36
	25	43	9	47
	35	37	4	59
	45	56	7	37
	55	49	7	44
Average		47	11	42
12	2	58	1	41
	15	65	8	27
	25	26	10	63
	35	49	2	49
	45	48	10	40
	55	39	4	56
Average		48	6	46
13	2	72	4	24
	15	73	7	21
	25	66	5	29
	35	79	2	18
	45	77	1	23
	55	71	6	23
	65	53	5	41
Average		70	4	26
14	10	45	6	49
	20	51	5	45
	30	50	6	45
	50	56	5	39
	60	41	4	54
	70	53	3	44
Average		49	5	46

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonite (%)
15	10	42	4	54
	20	53	4	43
	30	53	5	42
	50	49	4	48
	60	37	5	58
	70	32	3	64
	80	37	3	60
Average		43	4	53
16	2	39	9	52
	15	45	12	43
	25	33	12	54
	35	34	7	58
	50	31	5	64
	60	25	6	68
	70	46	2	52
	80	42	7	48
Average		37	8	55
17	10	31	2	68
	20	33	4	63
	30	46	2	52
	40	41	5	55
	50	38	7	55
	60	35	5	60
	70	34	2	64
Average		37	4	59
18	0	49	3	48
	10	39	6	55
	20	41	6	53
	30	48	8	44
	40	48	3	48
	50	48	2	50
	60	49	4	47
Average		46	5	49

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonit (%)
19	0	38	4	58
	10	51	3	46
	30	43	2	54
	40	35	12	53
	50	58	5	36
	60	37	8	59
	70	48	4	48
Average		39	5	56
20	0	34	6	60
	10	29	5	65
	20	12	13	75
	30	38	7	55
	40	31	5	64
	50	31	5	64
	60	26	9	65
	70	34	13	53
	80	44	5	51
Average		31	8	61
21	2	34	6	60
	15	33	6	60
	25	31	4	65
	35	34	9	58
	45	40	4	56
Average		34	6	60
22	0	42	3	55
	10	48	4	49
	20	47	12	41
	30	42	6	52
	40	34	6	60
	50	30	7	63
	60	32	6	62
	70	28	5	67
	80	36	14	50
Average		38	7	55

Core No.	Depth (cm)	Kaolinite (%)	Illite (%)	Vermiculite Chlorite Montmorillonite (%)
23	2	38	7	55
24	0	27	7	66
	10	45	12	43
	20	29	5	66
	30	38	10	51
	50	46	7	47
Average		37	8	55